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Conodont and Fusulinid Biostratigraphy and History of the Pennsylvanian to Lower Permian Keeler Basin, East-Central California

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ABSTRACT

The Pennsylvanian-Lower Permian Keeler Canyon Formation and lower part of the Lower Permian Lone Pine Formation in east-central California were deposited in a deep-water basin that originated in the Morrowan (Early Pennsylvanian), was fully established by the Desmoinesian (Middle Pennsylvanian), and lasted into the Sakmarian (Early Permian). Stratigraphic studies indicate that the Keeler Canyon Formation can be divided into members recognizable throughout the area of our detailed mapping. From older to younger they are the Tinemaha Reservoir, Tihvopah Limestone, Cerro Gordo Spring, and Salt Tram Members. Rocks in this basin, here referred to as the Keeler basin, contain numerous fusulinid and conodont faunas most of which were deposited by sediment-gravity flows probably originating at the margin of the Bird Spring carbonate platform to the northeast. Sixty-one species of Atokan to Sakmarian fusulinids and 38 species of Desmoinesian to Sakmarian conodonts are recognized. These, in addition to four species of Morrowan conodonts previously reported, show that every stage from the Morrowan to Sakmarian is represented in the basin. The fusulinid faunas are composed largely of taxa of the North American craton, especially the southwestern USA, with important endemic constituents and some McCloud Limestone forms, representing the Eastern Klamath terrane. Conodonts are closely similar to species in the Ural Mountains region of Russia and Kazakhstan, as well as the American midcontinent. The co-occurrence of fusulinids and conodonts in the Keeler basin results in a better correlation of zones based on these two groups of fossils than generally is possible.

INTRODUCTION

The Keeler basin, one of a succession of several late Paleozoic basins in east-central California, accumulated a thick, apparently continuous section of Pennsylvanian to Early Permian deep-water marine strata representing the southwesternmost exposures of fossiliferous rock of this age in the Cordilleran miogeoclone. Strata deposited in this basin, assigned to the Keeler Canyon Formation and lower member of the Lone Pine Formation, form an approximately north-south-trending belt about 70 km wide and at least 180 km long (Fig. 1). Coeval strata adjacent to the Keeler basin are represented by the shallow-water Mount Baldwin Marble to the northwest in the Sierra Nevada, which probably formed on an isolated carbonate platform, and the shallow-water Bird Spring Formation to the east in the southern Cottonwood Mountains and Panamint Range, which was part of a broad carbonate platform that fringed the western margin of the North American craton (e.g., Stone and Stevens, 1988; Stevens and Greene, 1999).

Regional mapping reveals that the Keeler Canyon Formation is more extensively exposed than the overlying Lone Pine Formation and therefore best marks the minimum extent of the Keeler basin. The Keeler Canyon Formation crops out most widely in the southern Inyo Mountains, but exposures extend northward to Mazourka Canyon and Tinemaha Reservoir, eastward into the Ubehebe Mine and Quartz Spring areas, and southward to the north end of the Slate Range (Figs. 1, 2).
Because both conodonts and fusulinids occur throughout the sequence, the rocks of the Keeler basin offer an unusually favorable opportunity for comparing the biostratigraphy of these two faunal groups that commonly do not occur together. The conodonts, many of which have worldwide distribution, allow correlation of the upper part of the Keeler basin section with the Czhelian (Upper Pennsylvanian) and the type Cisuralian (Lower Permian) in the southern Ural Mountains, and the fusulinids permit comparison with Pennsylvanian and Lower Permian sections in the United States midcontinent region. The paleogeographic position of the Keeler basin near the western edge of the late Paleozoic North American continent also makes these faunas critical for evaluation of relations between those of the North American craton and those of late Paleozoic terranes that were later accreted to the continental margin. Finally, detailed age control of rocks in this region is critical for dating the initiation of regional late Paleozoic contractual tectonism thought to have marked the transition from a transform to a convergent continental margin in east-central California (Stevens et al., 1998).

**SCOPE**

This report summarizes and updates stratigraphic and paleontologic information acquired by the authors over a period of many years. Our work has included geologic mapping of all major outcrop areas of Pennsylvanian and Permian rocks in the Inyo Mountains region, measurement of key stratigraphic sections, and paleontological studies of the fusulinids and conodonts. The paleontological data and interpretations presented here are based on the study of fusulinid (Stevens) and conodont (Ritter) samples collected by the authors. The lithostratigraphic information presented here is updated from previous reports (e.g., Stone, 1984; Stone and Stevens, 1984, 1987), although some is based on recent field work. The stratigraphic scheme used here is shown in Figure 3.

Much of this report is based on work in the Cerro Gordo Mine area of the southern Inyo Mountains where the Keeler Canyon and Lone Pine Formations are most completely and extensively exposed, and where the fusulinids are best preserved. We have mapped this area in detail (Fig. 4) and have measured and collected two stratigraphic sections to provide fusulinid and conodont control. A third stratigraphic section in this area (Section 3 on Fig. 4), measured and described by Riggs (1962) as part of a fusulinid study, was reexamined and partially recollected to provide additional fusulinid and conodont control. We also utilize a measured section of the Keeler Canyon and Lone Pine Formations in the Ubehebe Mine area that was collected for fusulinids and conodonts by Stone (1984).

Figure 1. Paleogeographic setting of the Keeler basin in east-central California. BCF=Bishop Creek pendant; CG=Cerro Gordo; DH=Darvin Hills; MC=Marble Canyon; MMP=Mount Morrison pendant; PB=Panamint Butte; QS=Quartz Spring; SRH=Santa Rosa Hills; TCH=Talc City Hills; TR=Tinemaha Reservoir; UM=Ubehebe Mine; WSC=Warm Spring Canyon.

Figure 2. Major outcrops of Keeler Canyon Formation. Additional small outcrops occur as far south as the north end of the Slate Range (Fig. 1). CM=Conglomerate Mesa; MC=Mazourka Canyon; SLC=San Lucas Canyon. For other abbreviations see caption for Figure 1.
The measured sections are shown in Figure 5 and are briefly described in Appendix 1. Samples from the measured sections are supplemented by spot samples from various other areas. In all, 67 fusulinid and 66 conodont collections are reported. The location and faunal content of these samples are tabulated in Appendix 2.

This study was initiated with the purpose of gaining a better understanding of the geologic history of this region, reporting on the nature of the conodont and fusulinid faunas, and providing illustrations of the major taxa encountered in our sampling. It is our intention here to provide a general outline of the paleontology of these faunas without presenting a detailed taxonomic study.

STRATIGRAPHY

Pennsylvanian and Lower Permian strata of east-central California received little attention prior to the work of Merriam and Hall (1957) who named the Keeler Canyon and Owens Valley Formations for exposures in the southern Inyo Mountains. Later Hall and MacKeveet (1962) used these units in mapping of the Darwin quadrangle, Merriam (1963) and D.C. Ross (1965) mapped these formations throughout much of the southern Inyo Mountains, and Burchfiel (1969) mapped them in the Dry Mountain area east of Saline Valley. Rocks equivalent to part of the lower Keeler Canyon Formation, a distinctive unit of fine-grained limestone containing spherical black chert nodules ("golf ball beds" of Merriam and Hall, 1957), previously had been mapped and named the Tihvipah Limestone in the northern Cottonwood Mountains near Quartz Spring (McAllister, 1952), and rocks equivalent to the Keeler Canyon and Owens Valley Formations in the Ubehebe Mine area (McAllister, 1956) were mapped as Bird Spring (?) Formation. The stratigraphy of the Keeler Canyon Formation and some of its lateral variations were discussed by Stevens et al. (1979).

Stone (1984) conducted a regional study of the Keeler Canyon and Owens Valley Formations and delimited the geographic extent of the Keeler basin, contrasting rocks in this basin with those on the largely coeval carbonate shelf to the east represented by the Bird Spring Formation. In that study the Keeler Canyon Formation was divided into four informal members, the second of which coincided with the "golf ball beds" of Merriam and Hall (1957) and the Tihvipah Limestone of McAllister (1952). The two upper members were later employed by Yose (1987), Yose and Heller (1989), and R.P. Miller (1989), who studied the sedimentary facies of these units.

Stone (1984) divided the overlying Owens Valley Formation into a Lower Permian and an Upper Permian part separated by an unconformity. Later, Stone and Stevens (1987) formally raised the Owens Valley Formation to group status and introduced the name Lone Pine Formation for the Lower Permian, mostly deep-water marine strata below the unconformity. The Lone Pine Formation is now divided into four informal members (A–D) and the Reward Conglomerate member (Stone et al., 2000).

Here, the Keeler Canyon Formation is subdivided into four formal members. The complete stratigraphic scheme now used for rocks of the Keeler basin and the enclosing units is shown in Figure 3.

KEELER CANYON FORMATION

The Keeler Canyon Formation consists predominantly of evenly bedded, silty to sandy and bioclastic limestone. In most areas this formation overlies black shale of the Upper Mississippian Rest Spring Shale, commonly along a faulted contact, and is conformably overlain by the Lone Pine Formation which consists largely of mudstone with a few normally graded limestones. In the Cerro Cordo Mine area (Fig. 4), the Lone Pine Formation pinches out southeastward along strike, and the Keeler Canyon Formation is unconformably overlain by Lower-Middle (?) Triassic rocks of the Union Wash Formation.

The type section of the Keeler Canyon Formation (Merriam and Hall, 1957) is east of the Estelle Tunnel portal in the Cerro Cordo Mine area. The upper part of this section, designated Section 3 in this report (Fig. 4), was measured by Riggins (1982). The type section is not ideal as the lower part is pervasively sheared and altered, there is a large sill with other possible structural compli-
Figure 4. Geologic map of Pennsylvanian and Lower Permian rocks and the enclosing strata in the Cerro Gordo Mine area showing location of measured Sections 1, 2, and 3.

cations in the middle, and the uppermost part is missing due to pre-Triassic erosion. To supplement the type section, we here designate Section 1 of this report, located between 1 and 2.5 km northwest of the Cerro Gordo Road (Fig. 4), as a structurally simpler and more complete reference section of the Keeler Canyon Formation. In this section, the Keeler Canyon Formation is conformably overlain by the Lone Pine Formation and has its maximum known thickness of 1,261 m. The basal Keeler Canyon beds are highly disturbed along a faulted contact with the Rest Spring Shale, but the remainder of the section is mostly undisturbed except by minor folding.
Figure 5. Lithostratigraphic correlation of sections measured in the Keeler basin. Numbers and capital letters refer to fossil samples. f indicates fusulinid sample; c indicates conodont sample. (See Appendix 2 for taxa present).

The Keeler Canyon Formation thins both northward and southeastward away from the Cerro Gordo Mine area (Stone, 1984); it is about 425 m thick at Coyote Spring in the vicinity of Independence 30 km to the northwest, and about 350 m thick east of Conglomerate Mesa 15 km to the southeast (Fig. 2). In the Ubehebe Mine area, the Keeler Canyon Formation has a measured thickness of 1,061 m (Stone, 1984) and is similar in lithology and completeness to sections in the Cerro Gordo Mine area (Fig. 5).

In this paper we formally name and describe four members of the Keeler Canyon Formation. They are the Tinemaha Reservoir, Tivhipah Limestone, Cerro Gordo Spring, and Salt Tram Members.

Tinemaha Reservoir Member

The lowest member of the Keeler Canyon Formation is here named the Tinemaha Reservoir Member for strata exposed near Tinemaha Reservoir southeast of Big Pine (Fig. 2). The type section is on a prominent ridge southeast of the reservoir where it is composed of about 400 m of bioclastic limestone, sandy to silty limestone, minor limestone conglomerate, and interbedded shale and siltstone (Stone, 1984). The limestone beds are laterally extensive and display graded bedding and Bouma sequences. The base of this member is placed at the base of the lowest thick limestone which conformably overlies the Rest
Spring Shale. It is conformably overlain by the Thivipah Limestone Member. Thick exposures of the Tinemaha Reservoir Member are restricted to the type area, but very thin sequences attributable to this member have been recognized elsewhere (e.g., the southernmost Darwin Hills).

Thivipah Limestone Member

The second member of the Keeler Canyon Formation is equivalent to the Thivipah Limestone of McAllister (1952) and is here referred to as the Thivipah Limestone Member. This unit is composed of medium- to dark-gray micritic limestone and light-gray to tan, silty or argillaceous limestone, both of which characteristically contain spherical to subspherical nodules of black chert generally between 0.5 and 2 cm in diameter. These cherty, fine-grained limestones differ from most other rocks in the Keeler Canyon Formation in generally lacking graded bedding and Bonna sequences. Scattered beds of bioclastic and conglomeratic limestone, however, are present locally. In addition to its type area near Quartz Spring, the Thivipah Limestone Member has been recognized in the Conglomerate Mesa area, the Coyote Spring area near Independence, the Tinemaha Reservoir area, and locally in the Cerro Gordo area. It ranges in thickness from about 30 to 140 m.

This unit lies conformably on the Tinemaha Reservoir Member, wherever that member is present, or evidently unconformably on the Rest Spring Shale. Throughout most of the central part of the Keeler basin, the Thivipah Limestone Member is missing because offaulting between the Rest Spring Shale and the Keeler Canyon Formation.

Cerro Gordo Spring Member

The Cerro Gordo Spring Member consists primarily of tan-weathering calcareous siltstone interbedded with medium- to dark-gray, fine-grained to bioclastic limestone. The bioclastic limestone typically occurs as graded beds 20 cm to 1.5 m thick; these beds are rich in echinodermal debris and locally contain fusulinids and conodonts. The type section of this member, which is faulted against the Rest Spring Shale, comprises the lower 428 m of Section 1 in the Cerro Gordo Mine area (Figs. 4, 5). The member name is derived from Cerro Gordo Spring near the crest of the Inyo Mountains about 6 km northwest of the Cerro Gordo Road (Fig. 4).

The Cerro Gordo Spring Member is also well developed near Ubehebe Mine, where it has a measured thickness of 231 m above a faulted base (Stone, 1984). There it contains thick limestone megabreccias described by Yose (1987) and Yose and Heller (1989). At Coyote Spring near Independence, where it is about 100 m thick (Stone, 1984), the Cerro Gordo Spring Member conformably overlies the Thivipah Limestone Member. In the Conglomerate Mesa area, the Cerro Gordo Spring Member is poorly developed and apparently consists of about 20 m of platy gray siltstone characterized by locally abundant bedding-parallel trace fossils (Stone, 1984).

Salt Tram Member

The uppermost part of the Keeler Canyon Formation is here named the Salt Tram Member in reference to an abandoned aerial tramway once used to transport salt across the Inyo Mountains from Saline Valley into Owens Valley. The ruins of the tramway cross the crest of the range about 10 km northwest of the Cerro Gordo Road. The Salt Tram Member, which differs from the Cerro Gordo Spring Member in containing many thick, coarse-grained, graded limestones, was previously referred to informally as the Mexican Spring member or unit (Stone, 1984; Yose and Heller, 1989; R.P. Miller, 1989), but the name Mexican Spring has since been formally applied to a nearby Mississippian formation (Stevens et al., 1996).

The Salt Tram Member conformably overlies the Cerro Gordo Spring Member. The base of the Salt Tram Member is placed at a point in the upper part of the Keeler Canyon Formation where thick limestone beds become predominant. This member is the thickest of the four members and is composed primarily of evenly bedded, medium- to dark-gray, silty to sandy limestone, bioclastic limestone, and conglomeratic limestone interbedded with thin-bedded to laminated gray, tan, and pink, calcareous mudstone and shale. Limestone beds are 25 to 50 cm thick on average but are as thick as 2 m. Beds are laterally extensive and characteristically display graded bedding, Bonna sequences, and flute and groove casts. Fusulinids are common to abundant in some bioclastic limestone beds.

The type section of the Salt Tram Member comprises the upper 833 m of the Keeler Canyon Formation in Section 1 in the Cerro Gordo Mine area (Figs. 4, 5). In this area, the Salt Tram Member is divided into a lower and an upper subunit. The lower subunit contains substantial amounts of calcareous mudstone and shale and the top is marked by a thick zone of relatively thin, fine grained, recessive beds. The upper subunit contains thin packages of resistant, mostly thick-bedded limestone separated by thinner intervals of recessive mudstone and shale. This subunit contains considerably less mudstone and shale than the lower subunit.

In the Ubehehe Mine section where the Salt Tram Member cannot be subdivided, this member is 830 m thick and contains several limestone conglomerates and limestone
megabreccia sheets (Stone, 1984; R.P. Miller, 1989). In the
northeastern part of the Keeler basin south of Mazourka
Canyon (Fig. 2) the Salt Tram Member is only about 225 m
thick and is finer grained. In the Conglomerate Mesa area,
limestone turbidites assigned to the Salt Tram Member
are about 300 m thick and sharply overlie platy siltstone
assigned to the Cerro Gordo Spring Member (Stone, 1984).

Undivided Cerro Gordo Spring and Salt Tram Members
at San Lucas Canyon.

The Keeler Canyon Formation is extensively exposed
in the vicinity of San Lucas Canyon on the east side of the
southern Inyo Mountains (Fig. 2). These complexly folded
rocks have an estimated thickness of about 1,200 m and
consist primarily of thin- to medium-beded limestone,
silty limestone, and calcarenite in which graded bedding,
cross lamination, and convolute lamination are locally
observed (Werner, 1979). Our mapping shows that in this
area the sharp basal contact of the formation with the Rest
Spring Shale is probably faulted. Except for a thin, locally
developed basal zone of cherty limestone that may repre-
sent the Tihvipah Limestone Member, the entire forma-
tion in this area is presumably equivalent to the Cerro
Gordo Spring and Salt Tram Members. However, in con-
trast to the Cerro Gordo and Ubehebe Mine areas, nei-
ther member is distinctly represented here and we are
unable to differentiate between them.

LONE PINE FORMATION

The Lone Pine Formation conformably overlies the
Salt Tram Member of the Keeler Canyon Formation. The
lower subunit of this formation (member A of Stone and
Stevens, 1987) is composed primarily of fine-grained,
thin-beded calcareous mudstone, siltstone, and very fine
grained sandstone. The overlying subunits of the Lone Pine
Formation (members B, C, D, and the Reward Conglomerate
Member) apparently were deposited after the Keeler
basin had been modified by an episode of contractile
deformation (Stevens and Stone, in press) and are not of
primary concern to this study. These higher subunits were
recently reviewed and interpreted by Stone et al. (2000).

Member A of the Lone Pine Formation is in excess of
1,000 m thick in the south-central Inyo Mountains (Stone
and Stevens, 1987) but thins southward toward the Cerro
Gordo Mine area. It is about 240 m thick at the type sec-
tion of the Lone Pine Formation 2.5 km north of the area
of Figure 4, thinning to 67 m in Section 1 where it is
unconformably overlain by Early Triassic rocks. This thin-
ing of member A resulted from pre-Triassic deformation
and erosion (Stone et al., 2000). Between Section 1 and
the Cerro Gordo Road, rocks assigned to the Lone Pine
Formation maintain an average thickness of 60 to 70 m,
the lower half of which consists of thin-beded calcareous
mudstone and siltstone typical of member A. The upper
half of the sequence in this area consists of resistant, fine-
grained limestone similar to some limestones in the Keeler
Canyon Formation. For unknown reasons these beds are
not present in Section 1 and areas farther north. To the
south, just north of the Cerro Gordo Road, this upper limest-
ene subunit is erosionally truncated beneath the Union
Wash Formation, and a short distance farther south the
underlying mudstone subunit is truncated (Fig. 4).

In the Ubehebe Mine area, rocks assigned to the Lone
Pine Formation are about 450 m thick with the top eroded
and comprise two subunits (Fig. 5). The lower subunit,
about 300 m thick, consists of thin-beded, fine-grained,
recessive calcareous to siliceous mudstone, siltstone, and
very fine grained sandstone similar to rocks typical of
member A of the Lone Pine Formation in the southern
Inyo Mountains. The upper subunit, about 150 m thick, is
composed of resistant limestone turbidites similar to those
of the underlying Salt Tram Member of the Keeler Canyon
Formation.

In the Conglomerate Mesa area, the Lone Pine Forma-
tion is absent and the Keeler Canyon Formation is uncon-
formably overlain by various units of the informally named
sedimentary rocks of Santa Rosa Flat (Maggiaetti et al.,
1988; Stone et al., 1989), some of which are equivalent in
age to parts of the Lone Pine Formation. Over much of
this area, the rocks directly above the Keeler Canyon
Formation are massive echiinodermal limestone compris-
ing unit 7 of the sedimentary rocks of Santa Rosa Flat. We
also have identified unit 7 limestone in a small outcrop
unconformably above the Keeler Canyon Formation in
San Lucas Canyon.

SEDIMENTOLOGY

Stevens (1970) was the first to interpret the Keeler Can-
yon Formation as a turbidite sequence composed largely of
graded beds containing a transported fauna of fusulinids
and other fossils alternating with very fine grained, unfos-
siliferous beds. Later sedimentologic, petrographic, and
sedimentary facies studies (Parker, 1976; Flora, 1984; Yose,
1987; R.P. Miller, 1989; Yose and Heller, 1989) have demon-
strated that the Keeler Canyon Formation represents a
submarine fan or a debris apron that accumulated downslo-
pe from an extensive, long-lived carbonate shelf or plat-
form. The overlying member A of the Lone Pine Formation
has been interpreted to represent deposition in a deep-
water basin plain environment mostly far removed from a
shallow-water source of carbonate debris (Stone and
Stevens, 1987).
Transported calcareous fossils, mostly pelmatozoan columns, fusulinids, and bryozoans, are abundant locally in the limestone turbidites and debris-flow beds of the Keeler Canyon Formation. On some bedding surfaces fusulindis are strongly aligned, commonly in a layer only a few fusulindis thick; in some beds, fusulindis are size-sorted with different species or different developmental stages of the same species in different layers. Conodonts are moderately abundant in many of these beds.

Fossils in the bioclastic beds evidently were derived from various shallow- to moderately deep-water environments and mixed during transport. In contrast, the fine-grained beds, even the densest micrites, lack not only calcareous fossils but also conodonts. In some of these beds, however, ghosts of radiolarians and siliceous sponge spicules suggestive of deep water have been noted.

Fossils, including both fusulindis and conodonts, are rare in member A of the Lone Pine Formation except in the locally developed limestone subunits and in a few thin limestone turbidites. The only other fossils that have been reported from member A are sponge spicules and calcispheres or calcified radiolarians in some micritic limestone beds (Stone, 1984).

Peleontology

Zonations and Ages

Ten informal fusulind zones (F1–F10) and nine informal conodont zones (C1–C9), interval zones of Oriol et al. (1983), are recognized in the rocks of the Keeler basin (Figs. 6–8). These informal zones do not designate bodies of rock containing continuous occurrences of particular species or genera or assemblages of species, but instead include sequences of rocks, many of which are devoid of fusulindis or conodont elements, bounded by beds containing the first occurrence of stratigraphically significant species or genera.

The informal zones recognized in the Keeler basin are here correlated with a chronostratigraphic scale (Figs. 6, 7) employing a combination of American and internationally adopted names. Names of American stages for the lower part of the Pennsylvanian are used here because the International Commission on Stratigraphy has yet to implement a formal international scale. For the uppermost Pennsylvanian we use the Russian stage name Gzhelian because that stage is more complete than the American equivalent, the Virgilian. For the Permian we follow the global chronostratigraphic scale recently approved by the Subcommission on Permian Stratigraphy, International Commission on Stratigraphy (Jin et al., 1997). Thus, we use the following stage names. From oldest to youngest they are: Morrowan, Atokan, Desmoinesian, Missourian, Gzhelian, Asselian, Sakmarian, and Artinskian.

Fusulinid Paleontology

Fusulindis have long been known from rocks of the Keeler basin but have received little attention. McAllister (1952, 1956) reported Fusulinella from the Tihviphah Limestone near Quartz Spring and Triticites, Pseudofusulina, and Schuagerina? from the Bird Spring (?) Formation near Ubehebe Mine, indicating an Atokan (early Middle Pennsylvanian) to Wolfcampian (Early Permian) age for these rocks that have since been reassigned to the Keeler Canyon Formation. Similarly, Merriam and Hall (1957) reported Fusulinella, Triticites, and Pseudofusulina from the Keeler Canyon Formation in the southern Inyo Mountains. Riggs (1962) described and illustrated fusulindis from 15 collections in the upper 650 m of the type section of the Keeler Canyon Formation in the southern Inyo Mountains. He assigned species to Pseudofusulina, Triticites, Schuagerina, and Pseudofusulina, indicating a Virgilian (late Late Pennsylvanian) to Wolfcampian age. Stone (1984) presented a preliminary report on the fusulindis from the Pennsylvanian and Permian rocks in the Inyo Mountains region, including a list of 30 taxa from the Keeler Canyon Formation and member A of the Lone Pine Formation, and illustrations of 24 of the species. These fusulindis, which included Pseudoschuagerina in addition to other genera reported previously, were interpreted to indicate an age of Atokan to early middle Wolfcampian. Most recently Stone et al. (2000) briefly described and illustrated some fusulindis from member A of the Lone Pine Formation and from member B of that formation, which is part of the overlap assemblage that postdates deformation of the Keeler basin.

The fusulindis identified for this study are mostly from the Cerro Gordo Mine area although collections from other areas also were used. In addition to collections reported for the first time here, all collections previously reported by Stone (1984) were reexamined and several localities originally reported by Riggs (1962) were collected. Most of the collections are from the Salt Tram Member of the Keeler Canyon Formation, in which fusulindis are locally very abundant. Fewer collections are from the Cerro Gordo Spring Member, only four are from the Tihviphah Limestone Member, and only one sample from the Tenemaha Reservoir Member contains fusulindis. Four collections of fusulindis from member A of the Lone Pine Formation also are reported.

Sixty-one fusulindis species identified for this study are listed and briefly described in Appendix 3, and are illustrated in Figures 9–11. Reduced photographs of some of the important species are shown in stratigraphic sequence in Figure 12. Many of the species encountered in our samples appear to be new, but because of the paucity of specimens of most species and poor preservation, no new
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<td>C7 CG-490; S-1752, -1794, -1795, -1796; U-45, -57, -61; 98-I-922?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F4 2785, 3115, 3549; S-1778; U-38</td>
<td>C6 CG-0; U-34.5, -36, -42.5; 98-I-926, 927, 928</td>
</tr>
<tr>
<td>Tinemaha Res. Tithyaq Ls. Cerro Gordo Spring Member</td>
<td>Upper Carboniferous</td>
<td>F3 S-0858</td>
<td>C5 U-17, -18, -25, -26, -31</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Desmoinesian</td>
<td>F2 149, 360; S-1389b, S-1773; 82-I-31; GH-1, -2, -5</td>
<td>C2 149A, 360A, 680A; U-5A, -7, -9, -11; 82-I-28, -29, -30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atokan</td>
<td></td>
<td>F1 S-1208, -1225</td>
<td>None</td>
</tr>
<tr>
<td>Morrowan</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6. Correlation of fusulinid and conodont zones recognized in the Keeler basin indicating samples assigned to each zone.
taxa are described at this time. Instead, most specimens from our study area are compared with similar species previously described.

Local fusulinid zones and regional correlations

The fusulinid zones recognized here can be generally correlated with fusulinid faunas from other parts of North America (Table 1). We base our correlations mostly upon our own interpretations of fusulinid faunal relationships modified to some extent by consideration of the detailed correlations of Ross and Ross (1999).

**Fusulinid Zone F1.**—This zone in the Keeler Canyon Formation is conceived to be equivalent to the widely recognized Zone of *Fusulinella* (Thompson, in Loeblich and Tappan, 1964) in North America. Species in the Keeler Canyon Formation include *Fusulinella fugax* and *Pseudostaftella* cf. *P. powowoensis*.

**Fusulinid Zone F2.**—This zone corresponds to the Desmoinesian stage in the United States and is characterized by several species of *Beedeina* and *Wedekindellina*. Species recognized include *Beedeina* aff. *B. acme*, *B. cf. B. apachensis*, *B. cf. B. capsensis*, *B. aff. B. havorthi*, *B. aff. B. occultifons*, *B. sp. 1*, *Wedekindellina* cf. *W. cabezasensis*, and *W. sp. 1*.

**Fusulinid Zone F3.**—This zone was conceived to correspond to the Missourian stage in the United States. Unfortunately it is recognized only on the basis of speci-
<table>
<thead>
<tr>
<th>CHR.</th>
<th>LITH.</th>
<th>I.Z.</th>
<th>&quot;STANDARD&quot; ZONES</th>
<th>RANGE CHART</th>
<th>FAUNA</th>
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<tr>
<td></td>
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<tr>
<td>PERMIAN</td>
<td></td>
<td></td>
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<tr>
<td>Upper</td>
<td>Asselian</td>
<td>Lone Pine</td>
<td>C9</td>
<td>M. lata</td>
<td>upper unornamented Streptognathodus &amp; primitive Sweatognathus fauna</td>
</tr>
<tr>
<td>Upper</td>
<td>Asselian</td>
<td>Salt Tram Member</td>
<td>C8</td>
<td>M. uralensis, S. postfusus, S. fusus, S. constrictus-S. bariskoii, S. cristellaris, S. isolatus</td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>Gzhelian</td>
<td>C7</td>
<td>S. tenuialveus</td>
<td>Wardlawella</td>
<td>lower unornamented Streptognathodus fauna</td>
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<tr>
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<td>C6</td>
<td>S. virgilocus-S. pawhuskaensis</td>
<td>Neogognathodius</td>
<td>lower ornamented Streptognathodus fauna (deep troughs)</td>
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<td>C5</td>
<td>S. firmus, S. gracilis</td>
<td>Streptognathodus</td>
<td>nodose Neogognathodius fauna</td>
</tr>
<tr>
<td>Upper</td>
<td>Gzhelian</td>
<td>C4</td>
<td>S. confragus, S. cancellousus</td>
<td>Idiognathodius</td>
<td>mixed Neogognathodius Idiognathodius fauna</td>
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<tr>
<td>Upper</td>
<td>Gzhelian</td>
<td>C3</td>
<td>I. eccenticus, I. sveciferus</td>
<td>Idiognathodius</td>
<td>mixed Declinognathodus Idiognathodius Idiognathodius fauna</td>
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<tr>
<td>Upper</td>
<td>Gzhelian</td>
<td>C2</td>
<td>I. nodocarinatus</td>
<td>Rhachistognathodus</td>
<td>mixed Rhachistognathodus Declinognathodus Idiognathodius Idiognathodius fauna</td>
</tr>
</tbody>
</table>

| LATE |       |      |                  |             |       |
| LATE | Atokan | Tithyphath Ls. Mbr. | C1 | I. expansus, I. n. sp. 2 of Ritter et al. (in press), I. amplificus-I. obliquus | Rhachistognathodus Declinognathodus Idiognathodius |
| LATE | Morrowan | Tinemaha Res. Member |      | No widely recognized conodont zones | Neogognathodius |
| LATE | Morrowan | Tithyphath Ls. Mbr. |      | I. ouachitensis, Id. convexus, I. klapperei, Id. simousis, N. bassleri, N. symmetricus, Id. sinuatus-Rh. minicus, Rh. primus | Idiognathodius |
mens from a single random sample. None of the fusulinids at the appropriate stratigraphic position in measured sections are identifiable. Simple species of Triticites, including *T. burgessae*, are considered to belong to this zone.

**Fusulinid Zone F4.**—Zone F4 is characterized by the appearance of large species of *Triticites*, some of them highly inflated. Species present in the Keeler Canyon Formation include *Triticites californicus*, *T. cf. T. hermanni*, *T. aff. T. hollbensi*, *T. whetstonensis*, and *T. sp. 2*.

A similar fauna occurs in Beds 289–92A in the Bird Spring Formation in southern Nevada (Rich, 1961), suggesting a similar age, and *T. whetstonensis* allows correlation with the lower part of the Earp Formation in southern Arizona. *Triticites* sp. 2 in the Keeler basin is similar to *T. turgida* which occurs in bed H of the Captant Formation (C.A. Ross, 1965) in the Glass Mountains which Ross correlated with the middle Cisco Group of central Texas and the Shawnee Group in the midcontinent region. A form very close to *T. whetstonensis* occurs in the upper Cisco (Ross and Tyrell, 1965), which was correlated by C.A. Ross (1965) with the upper part of the Wabaunsee Group in the midcontinent. Based on the overall fauna we also correlate Fusulinid Zone F4 with the Admire Group in Kansas as shown by Thompson (1954). The presence of *Triticites* cf. *T. hermanni* in the Keeler basin suggests correlation with Zone A of the McCloud Limestone in the Klamath Mountains (Skinner and Wilde, 1965). The faunas in these rocks are typically Virginian.

**Fusulinid Zone F5.**—Large, inflated species of *Triticites* continue to be the dominant forms in this zone, but they are accompanied by small, unidentified species of *Schwagerina* with low, irregularly folded septa. Besides species of *Schwagerina*, this fauna includes *Pseudofusulinella* sp. 1, *Triticites* aff. *T. beedeli*, *T. cellamagnus*, *T. confertoides*, possibly *T. cf. T. hermanni*, *T. aff. T. kelleyensis*, *T. pinguis*, *T. aff. T. ventricosus* var. *sacramentoensis*, *T. sp. 2*, *T. sp. 3*, *T. sp. 4*, and a form resembling *T. burgessae*.

These faunas suggest correlation with Beds 90A–62A of the Bird Spring Formation in southern Nevada (Rich, 1961), “post-Virginian” beds of Sabins and Ross (1963) near or at the base of the Earp Formation in Arizona, and bed J of C.A. Ross (1965; Bed 2 of the Gray Limestone Member) of the Captant Formation in the Glass Mountains, which according to Wilde (1971) contains *Schwagerina*. Most of the Pueblo Formation in north-central Texas and the lower half of the Council Grove Group in Kansas also probably correlate with Fusulinid Zone F5 on the basis of the overall similarity of the faunas, consisting of largely of species of *Triticites* with generally small, primitive species of *Schwagerina*. It is uncertain whether or not this zone is represented in the Klamath Mountains section. The lack of primitive species of *Schwagerina* in that section suggests that an equivalent of this zone may be missing, and Skinner and Wilde’s (1965) observation that there is an apparent discordance between Zones A and B there strengthens this interpretation. These faunas commonly have been considered post-Virginian or Wolfcampian. Here, this fauna is considered Czhelian (latest Carboniferous) on the basis of the composition of both the fusulinid and associated conodont faunas (see later).

**Fusulinid Zone F6.**—This zone is characterized by a wide variety of inflated species of *Triticites* and moderately large, inflated species of *Schwagerina* having regularly and highly folded septa. Species include *Pseudofusulinella* sp. 1, *Schwagerina aculeata*, *S. modica*, *S. sp. 3*, *Triticites cellamagnus*, *T. confertoides*, *T. aff. T. directus*, *T. aff. T. hollbensi*, *T. meeki*, *T. pinguis*, *T. aff. T. ventricosus* var. *sacramentoensis*, *T. sp. 3*, *T. sp. 4*, and *Reticulosepta*? sp. 8.

---

Figure 9. Illustrations of fusulinid taxa recognized in this study. 1, Pseudostaffella cf. P. powowwensis (Thompson) from locality S-1223, x20 (SJS 89f); 2, Beedeina cf. B. apachensis (Ross and Sabins) from locality CH-1, x10 (SJS 83f); 3, Beedeina cf. B. cappaensis (Stewart) from locality 82-I-31, x10 (SJS 84f); 4, Beedeina aff. B. haworthi (Beede) from sample 149, x10 (SJS 85f); 5, Beedeina aff. B. occultima (Alexander) from sample 149, x10 (SJS 86f); 6, Beedeina sp. 1 from locality 82-I-31, x10 (SJS 87f); 7, Beedeina aff. B. acme (Dubnay and Henbest) from locality S-1773, x10 (SJS 88f); 8, Pseudofusulinella simplex Skinner and Wilde from locality S-97-CM-84, x10 (SJS 89f); 9, Fusulinella fugax Thompson from locality S-1208, x20 (SJS 90f); 10, Pseudofusulinella sp. 1 from locality S-1747, x20 (SJS 91f); 11, Pseudofusulinella parva Skinner and Wilde from locality S-1747, x20 (SJS 14f); 12, Wedekindellina aff. W. caezaensis Ross and Sabins from locality CH-2, x10 (SJS 92f); 13, Wedekindellina sp. 1 from sample 360, x10 (SJS 93f); 14, Triticites aff. T. beedeli Dunbar and Condra from sample 2292, x10 (SJS 94f); 15, Triticites burgessae Burma from locality S-0585, x10 (SJS 95f); 16, Triticites aff. T. hollbensi Thompson, Vercrive, and Bissell from sample 3115, x10 (SJS 96f); 17, Triticites aff. T. directus Thompson from sample 1390, x10 (SJS 97f); 18, Triticites aff. T. hermanni Skinner and Wilde from sample 3549, x10 (SJS 98f); 19, Triticites sp. 2 from sample 2665, x10 (SJS 99f); 20, Triticites aff. T. kelleyensis Needham from locality S-1753, x10 (SJS 100f); 21, Triticites mulieri Skinner and Wilde from locality S-1700, x10 (SJS 101f); 22, Triticites meeki Thompson from locality S-1747-CM-84, x10 (SJS 102f); 23, Triticites pinguis Dunbar and Skinner from locality S-1752, x10 (SJS 103f); 24, Triticites aff. T. ventricosus var. sacramentoensis Needham from locality S-0656, x10 (SJS 104f); 25, Triticites whetstonensis Ross and Tyrell from sample 3549, x10 (SJS 105f); 26, Triticites sp. 1 from locality S-79-CM-84, x10 (SJS 106f); 27, Triticites californicus Thompson and Hazzard from sample 3549, x10 (SJS 107f); 28, Triticites sp. 3 from locality S-1770, x10 (SJS 108f); 29, Triticites confertoides Ross from locality S-1752, x10 (SJS 109f); 30, Reticulosepta? sp. 8 from locality S-1759, x10 (SJS 110f).
Zone F6 is correlated with the highest beds in the Earp Formation assigned a post-Virgilian age by Sabins and Ross (1963). This interpretation is based on the presence of *Schwagerina cercellae* in the Earp Formation, a species quite similar to *S. aculeata* and probably about the same age. *Schwagerina cercellae* also occurs in the middle Council Grove Group in Kansas (Thompson, 1954), indicating correlation with those beds. The presence of the highly inflated species of *Schwagerina*, *S. ventricosa*, in Zone B in the Klamath Mountains also suggests correlation with Fusulinid Zone F6. The presence of *S. aculeata*, which in the Providence Mountains in southeastern California occurs with *Pseudoschwagerina* (Thompson et al., 1946), indicates that this zone is Permian in age.

**Fusulinid Zone F7.**—This zone is marked by the appearance of *Pseudoschwagerina*. Inflated specimens of *Triticites* are still common. Species include *Pseudofusulinella simplex*, *Pseudoschwagerina* cf. *P. needhami*, *P. aff. rhodesi*, *Schwagerina dunnensis*, *S. sp. 1*, *S. sp. 3*, *Triticites cellulamagus*, *T. meeki*, *T. pinguis?*, *T. aff. T. ventricosus var. sacramentensis*, and *T. sp. 1*.

Zone F7 probably correlates with much of the Earp Formation in southern Arizona (Sabins and Ross, 1963), in which inflated species of *Triticites* are also still common. Zones C and D in the Klamath Mountains are correlated with Fusulinid Zone F7 on the basis of the first appearance of *Pseudoschwagerina* (in Zone C), and the presence of *Pseudofusulinella simplex* (in Zone D). Zone D also contains *Paraschwagerina magna*, which is similar to *P. gigantea* from the Neal Ranch Formation, suggesting correlation with part of that unit. These faunas are considered Wolfcampian throughout North America.

**Fusulinid Zone F8.**—This zone is marked by the appearance of a primitive species of *Eoparafusulinula* resembling, but more primitive and probably slightly older than, *E. gracilis* from the Klamath Mountains. Other species include *Reticulocepta?* *sp. 6*, *Schwagerina aff. S. andresensis*, *S. aff. S. subletensis*, and *S. sp. 3*. *Eoparafusulinula aff. E. gracilis* suggests correlation with Zone E of the McCloud Limestone. Typical *Eoparafusulinula* is considered Sakmarian by V. Davydov (pers. commun, 2000), but this very primitive form may instead be Asselian as suggested by the associated conodonts (see later).

**Fusulinid Zone F9.**—This zone is marked by the appearance of typical forms of *Eoparafusulinula* (*E. sp. 1*), *Steuardina*, many species of *Reticulocepta*, and species of *Schwagerina* with intensely folded septa, including a form somewhat similar to *S. bellula*. Species include *Pseudofusulinella parvula*, *Reticulocepta* sp. 1, *R. ? sp. 2*, *R. ? sp. 3*, *R. ? sp. 4*, *R. ? sp. 5*, *R. ? sp. 6?*, *R. sp. 7*, *Schwagerina aff. S. andresensis*, *S. aff. S. arpa*, possibly *S. bellula*, *S. aff. S. subletensis*, *S. turgida*, *S. sp. 1*, *Steuardina sp. 1*, *S. sp. 3*, *S. ? cf. S. ? aff. Laxissima*, *Chusennella cf. C. jecetti*, *Pseudoschwagerina aff. P. parvus*, possibly *Pseudofusulinula decorva*, and *Eoparafusulinula sp. 1*.

*Eoparafusulinula sp. 1* is similar to species of the genus described by Ross (1967) from the upper part of the Neal Ranch Formation suggesting correlation with that part of the Glass Mountains section. *Steuardina*, represented by *S. texana*, also first appears in the Neal Ranch Formation (Ross, 1963; pers. comm., 2000). *Schwagerina turgida* and *S. aff. S. arpa* in Fusulinid zone 9 suggest correlation with zone F in the Klamath Mountains, but the presence of the form similar to *S. bellula*, which compares with *Paraschwagerina fax* and *P. elongata*, and *Pseudofusulinula decorva* suggest correlation with Zone E. We prefer correlation with Zone E because it is more compatible with our correlation of Fusulinid Zone 10.

**Fusulinid Zone F10.**—This zone is distinguished by delicate, inflated species of *Schwagerina*, especially *S. bellula*. Other species represented include *Pseudofusulinella parvula*, *Pseudofusulinula decorva*, *Schwagerina aff. S. andresensis*, *S. turgida*, *S. sp. 2*, *Steuardina sp. 2*, and possibly *Reticulocepta?* sp. 6.

Fusulinid Zone F10 contains several species in common with Fusulinid Zone F9, but lacks the profusion of species of *Reticulocepta* present in the lower zone.

*Schwagerina* cf. *S. bellula* suggests correlation with the upper Neal Ranch Formation or the younger Lenox Hills Formation (Ross, 1963). This species is reported to extend
through a considerable thickness of beds in the Hueco Canyon Formation in the Franklin Mountains (Williams, 1966), but the type specimens were collected from the basal beds of the Hueco Limestone in the Hueco Mountains (Dunbar and Skinner, 1937). There, this species and Stewartina aff. *S. texana* occur in beds below those containing the coral *Stylostraea* sp. (Larry Wollschlager, per. commun., 1975). In the Franklin Mountains *Stylostraea* also occurs above most of the occurrences of *S. bellula*, although Williams (1966) reported it higher in the section. Similarly, in northeastern Nevada, the upper part of the Riepe Spring Limestone, which contains *Stylostraea* spp.,
Table 1. Correlation of fusulinid zones with important sections in North America modified according to some conodont data.

<table>
<thead>
<tr>
<th>Series boundaries based on conodont faunas (Ural Mountains)</th>
<th>Correlations based largely on fusulinid faunas and stratigraphic position</th>
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<tr>
<td>Keeler Basin (this study)</td>
<td>Keeler Basin (this study)</td>
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<tr>
<td>Lone Pine Fm.</td>
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<td>samples 15–25 &quot;Wolfcampian&quot;</td>
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<td>Zone F7</td>
<td>bed 32A?</td>
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<td>Zone F6</td>
<td>samples 70b &quot;post-Virgilian&quot;</td>
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<td>Zone F5</td>
<td>bed J</td>
</tr>
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<td>Zone F4</td>
<td>beds 90A–62A &quot;post-Virgilian&quot;</td>
</tr>
<tr>
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<td>beds 289–92A &quot;Virgilian&quot;</td>
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<td>Zones A</td>
</tr>
<tr>
<td>Zone F4</td>
<td>Zones A</td>
</tr>
</tbody>
</table>

STEVENS, STONE, RITTER, PENNSYLVANIAN-PERMIAN KEELER BASIN
was shown by Stevens et al. (1979) to lie above a zone referred to as the zone of *S. bellula*.

In most areas *Eoparafusulina linearis* makes its debut a short distance above *Stylasmaera*. This species occurs in the Lenox Hills Formation, at the top of the Hueco Canyon Formation in the Franklin Mountains, and at the base of the Rib Hill Sandstone immediately above the Riepe Spring Limestone in Nevada. In both of the latter two areas, *E. linearis* lies above the zone of *Stylasmaera*. Beds containing *Stylasmaera* and the slightly younger beds containing *E. linearis* can be correlated throughout northeastern Nevada and West Texas. Thus, the lower Hueco Canyon Formation in the Franklin Mountains, upper Riepe Spring Limestone in Nevada, and upper Neal Ranch Formation in the Glass Mountains are approximately the same age. According to Wardlaw et al. (1998) much of the Neal Ranch is Sakmarian in age, and Wardlaw and Davydov (2000) indicate that the highest part of the Riepe Spring Limestone also is Sakmarian. Both *Stylasmaera* and *E. linearis* also occur in the post-Keeler basin overlap assemblage in east-central California (Maggiolini et al., 1988). Therefore, Fusulinid Zone F10 in the Keeler Canyon Formation probably correlates with the *S. bellula* zone elsewhere and is Sakmarian, an age confirmed by the associated conodont assemblages (see later).

Excellent specimens of *Schwagerina* cf. *S. bellula* and *Pseudofusulina decora* suggest correlation with Zone E of the Klamath Mountains. These faunas have been considered Wuchiapingian in age in other parts of North America.

**CONODONT PALEONTOLOGY**

Conodonts from the Keeler Basin previously have been less extensively studied than the fusulinids. Stone (1984) reported Morrowan (Early Pennsylvanian) conodonts from near the base of the Keeler Canyon Formation (Tinemaha Reservoir Member) in the Tinemaha Reservoir area and Middle and Late Pennsylvanian conodonts from several samples in the Cerro Gordo Spring Member in the Ubehebe Mine area. Morrowan conodonts also were reported by C.D. Miller (1989) from a thin sequence of rocks assigned to the Keeler Canyon Formation in the southern Darwin Hills. More recently Ritter (1992) reported conodonts ranging in age from Missourian (Late Pennsylvanian) to Asselian (Early Permian) from the upper 850 m of the Keeler Canyon Formation in the Cerro Gordo Mine area (Section 2, Figs. 4, 5), including three species originally described from the middle Asselian of the southern Ural Mountains. No conodonts have been reported previously from member A of the Lone Pine Formation.

Sixty-six conodont collections containing 37 species (Figs. 13–17) were obtained from sampling of the Keeler Canyon and lower Lone Pine Formations. These samples are neither geographically nor stratigraphically uniform. For example, the Tinemaha Reservoir Member is represented by a single sample from its type locality. Six samples from the Tihvipah Limestone Member, all from near Quartz Spring, produced conodont elements. The majority of our collections resulted from systematic sampling of the Cerro Gordo Spring Member, Salt Tram Member, and Lone Pine Formation in the Cerro Gordo and Ubehebe Mine areas. At these localities, conodont-bearing beds are separated by much thicker intervals of barren strata. Faunas throughout the section are dominated by Pa elements of *Idiognathodus* and *Streptognathodus*. A minor percentage of samples from the upper two members of the Keeler Canyon Formation contained small numbers of reworked Devonian and Lower and Middle Pennsylvanian conodont elements.

Conodonts from the Keeler basin are here grouped into nine zones and correlated with a "composite standard" zonation (Fig. 8) based on the existing zonations of Barrick and Boardman (1989), Ritter (1995), and Chernykh and Ritter (1997). This zonation is based on the Pennsylvanian to Early Permian evolutionary model that follows.

**Conodont evolutionary model**

The Pennsylvanian and Early Permian represent a time of low conodont diversity coinciding with the rise and fall of the family Idiognathodontidae. The seminal genus *Declinognathodus* (Fig. 8) evolved from *Gnathodus girtyi* at the beginning of the Pennsylvanian Period (Sweet, 1988). With the successive addition of *Idiognathoides*, *Neognathodus*, and *Idiognathodus*, Idiognathodontidae reached its maximum generic diversity by late Morrowan time. Speciation events within these genera (as well as non-idiognathodontid *Rachistognathus*) provide the primary means for zoning Morrowan strata (Fig. 8). From its late Morrowan acme, diversity began to decline beginning with the late Morrowan extinction of *Rachistognathus*, followed by *Declinognathodus* and *Idiognathoides* during the middle and late Atokan, respectively. These evolutionary events are reflected in the transition from mixed *Rachistognathus*, *Declinognathodus*, *Idiognathoides*, *Neognathodus*, and *Idiognathodus* faunas in the Morrowan Series (Fig. 8), to mixed *Declinognathodus*, *Idiognathoides*, *Neognathodus*, and *Idiognathodus* faunas in the Atokan Series, to mixed *Neognathodus* and *Idiognathodus* faunas in the Desmoinesian Series. With the demise of *Neognathodus* in the beginning of the Missourian, *Idiognathodus* was temporarily the sole surviving idiognathodontid and most useful zonal index for Desmoinesian through early.

*Figure 12. Reduced photographs of important fusulinid species arranged in stratigraphic order.*
Figure 13. Desmoineian Pa elements from the Cerro Gordo Spring Member of the Keeler Canyon Formation. All specimens X60 unless otherwise noted. 1, 2, 5, 6, Gondolella magna Stauffer and Plummer, 1, sample 149a, X65, BYU 2K00110; 2, sample 149A, X65, BYU 2K00101; 5, sample 82-I-28, BYU 2K00102; 6, sample 82-I-28, BYU 2K00103; 3, Neognathodus mediusculitus Merrill, sample U-9, BYU 2K00104; 4, Neognathodus mediusculitus Merrill, sample 82-I-28, BYU 2K00105; 7-9, 13, 14, Idiognathodus nodocarinatus (Jones), all from sample 82-I-28 except 8, which is from sample 149A, 7, X65, BYU 2K00106; 8, X65, BYU 2K00107; 9, BYU 2K00108; 13, BYU 2K00109; 14, BYU 2K00110; 10-12, Idiognathodus obliquus Kositskaya, 10, sample U-5a, X 55, BYU 2K00111; 11, sample U-7, BYU 2K00112; 12, sample U-11, BYU 2K00113; 15, Neognathodus bothrops Merrill, sample 82-I-30, BYU 2K00114; 16, 17, Idiognathodus expansus Stauffer and Plummer, 16, sample 82-I-30, BYU 2K00115; 17, sample U-11, BYU 2K00116.
Missourian strata. During the latter part of the early Missourian, *Idiognathodus* gave rise to the fifth and final idiognathodontid genus, *Streptognathodus*.

*Streptognathodus* is the primary means for zoning and correlating middle Missourian through Asselian (Early Permian) strata on a global basis. Missourian streptognathodontid populations were characterized by species with ornamented platforms and deep medial troughs (lower ornamented *Streptognathodus* fauna of Figure 8). These were abruptly replaced by unornamented forms in the Gzhelian (lower unornamented *Streptognathodus* fauna). From these, a remarkably variable group of broad, heavily ornamented species (upper ornamented *Streptognathodus* fauna) emerged in the latest Gzhelian and continued into the middle Asselian. Included in this group are *S. wabaunseeensis*, *S. isolatus*, *S. noduliformis*, *S. flangulatus*, and *S. cristellaris*. The first occurrence of *S. isolatus* (developed from *S. wabaunseeensis*) defines the Carboniferous-Permian boundary (Chernyk and Ritter, 1997; Davydov et al., 1998). In the Asselian, the extinction of the nodose streptognathodontids left behind a low diversity fauna of unornamented morphotypes including *S. longissimus*, *S. constrictis*, *S. fuscus*, and *S. barskovi*. These were joined by the semial species of both *Sweeetognathus* and *Mesogondolella*, the chief index conodonts of the Permian System. Following Wardlow and Davydov (2000), the Asselian-Sakmarian boundary is placed at the appearance of *Sweeetognathus merrilli* (base of Conodont Zone C9).

**Local conodont zones**

Nine local conodont zones can be recognized and generally correlated with conodont zones previously recognized.

**Conodont Zone C1.**—This zone is characterized by the presence of generalized species of *Idiognathodus* and *Neognathodus*. The association of *Idiognathodus* and *Neognathodus* in the absence of *Rhachistognathus*, *Declinognathus*, *Idiognathoides*, and *Streptognathodus* suggests a late Atokan to Desmoinesian age and corresponds with the upper Atokan to Desmoinesian mixed *Neognathodus*-Idiognathodus fauna (Fig. 8).

**Conodont Zone C2.**—The base of this zone, which corresponds with the upper part of the Desmoinesian stage, is defined by the first occurrence of *Idiognathodus nodocarinatus*. Associated species include *I. expansus*, *I. obliquus*, *Gondolella magna*, and *Neognathodus medexulimus*. This zone is correlated with the *I. nodocarinatus* zone of the "standard" zonation.

**Conodont Zone C3.**—The lower boundary of Conodont Zone C3 is marked by the first occurrence of *Idiognathodus sulciferus* of the lower Missourian *I. sulciferus* zone. *I. expansus* is still an important element of zonal faunas.

**Conodont Zone C4.**—The base of this middle Missourian zone coincides with the first occurrence of *Streptognathodus cancellatus*. The top is defined by the appearance of *S. elegantulus*. *Streptognathodus sulciferus* ranges throughout the zone and *S. confugratus* appears in the upper part. Zone C4 correlates with the combined *S. cancellatus* and *S. confugratus* Zones of the North American midcontinent.

**Conodont Zone C5.**—The highest Missourian strata comprise Conodont Zone C5. This zone is characterized by elements of *Streptognathodus elegantulus* and *S. excelus* in association with *Idiognathodus magnificus*. This conodont zone is correlated with the *S. gracilis* fauna of Barrick and Boardman (1989) on the basis of *S. elegantulus* and *S. excelus*.

**Conodont Zone C6.**—This zone corresponds to the lower half of the Gzhelian stage and the *Streptognathodus virglicus-S. paushuskaensis* conodont zone of the American midcontinent as indicated by the dominance of *S. paushuskaensis*. The appearance of this species defines the base of the *S. paushuskaensis-S. virglicus* zone. Accompanying *S. paushuskaensis* are specimens of *S. virglicus*, *S. excelus*, and *S. browneiwillensis*.

**Conodont Zone C7.**—This upper Gzhelian zone is characterized by the appearance of unornamented streptognathodonts such as *Streptognathodus tenutaleus*, *S. aff. S. longilatus*, *S. n.sp. A* of Chernyk and Ritter (1997), and *S. costaealbellus* in conjunction with *S. paushuskaensis*. These Keeler Canyon faunas correspond with the middle to upper Gzhelian *S. tenutaleus* Zone of Chernyk and Ritter (1997). In both the American midcontinent and southern Ural Mountains, uppermost Gzhelian strata contain a zone of ornamented streptognathodonts (*S. wabaunseeensis* Zone). Due to the conodont-poor nature of latest Gzhelian rocks, this zone is not distinguishable in the Keeler basin. Hence, middle to upper Gzhelian strata are assigned to Zone C7 as defined herein.

**Conodont Zone C8.**—The base of this zone corresponds with the appearance of *Wardlawella expansa*. Other species include *Streptognathodus constrictus*, *S. aff. *S. barskovi*, *S. fuscus*, *S. aff. S. cristellaris*, *Mesogondolella dentisepara*, and *M. belladontae*. This zone is considered to be Asselian in age and the base of this zone corresponds roughly with the Pennsylvanian-Permian boundary. Sample 765 near the top of this zone in Cerro Gordo Section 1 contains *Wardlawella expansa* and a form transitional between *W. expansa* and *Sweeetognathus merrilli*, a Sakmarian species. We consider this sample to be upper Asselian.

**Conodont Zone C9.**—The appearance of *Sweeetognathus merrilli* defines the base of conodont zone C9. *Mesogondolella lata* also occurs in these samples. *Sweeetognathus merrilli* has a range of lower to upper Sakmarian
and Mesogondolella lata a range of upper Asselian through lower Sakmarian. Therefore Conodont Zone C9 is considered early Sakmarian in age.

Conodont correlations

On the basis of correlation of the local conodont zones with the “composite standard” zonation and with the local fusulinid zones, fusulinid-bearing stratigraphic sections throughout North America presumably can be correlated with the standard Ural Mountains section (Table 1). Conodont work in the midcontinent United States and Texas (Barrick and Boardman, 1989; Ritter, 1995; Barrick et al., 1996; Wardlaw and Davydov, 2000) is mostly consistent with these correlations. Chernyk and Ritter (1997) and Davydov et al. (1998) placed the Carboniferous-Permian boundary at the base of the Bennett Shale (middle Council Grove Group) in Kansas and within the Gray Limestone Member of the Gaptank Formation in the Glass Mountains. The former correlation is compatible with our correlations in the Keeler basin, but on the basis of the poorly known fusulinid data we tentatively place the the Gray Limestone (Bed J of C.A. Ross, 1965) in the upper Gzhelian. Wardlaw and Davydov (2000) placed the Asselian-Sakmarian boundary within the Neal Ranch Formation, a position compatible with our correlations. In the Kansas section, Wardlaw and Davydov (2000) placed the Asselian-Sakmarian boundary at the base of the Eiss Limestone (in the upper part of the Council Grove Group). Because of the lack of fusulinids in this part of the Kansas section we cannot evaluate this placement.

FAUNAL AFFINITIES

The fusulinids of the Keeler basin consist of a mixture of North American, McCloud Limestone, and endemic species, with North American cratonic species dominating. Zone F2 (Atokan) through Zone F5 (late Gzhelian) fusulinid faunas are composed of typical North American cratonic species with only a few endemic and McCloud Limestone forms. In Fusulinid Zone F6 (upper Gzhelian to lower Asselian) and again in Fusulinid Zone F9 (upper Asselian-lower Sakmarian), however, endemic fusulinids are dominant. McCloud Limestone fusulinid species are prominent in Fusulinid Zones F8 and F9 (upper Asselian and lower Sakmarian). In Zone 10, McCloud fusulinid species persist but endemic species are sparse.

Of the fusulinid species from the Keeler basin with North American cratonic affinity, many compare rather closely with those of south-central United States. Considering the proximity of the Bird Spring carbonate platform immediately east of the Keeler basin, it is surprising that only a few species from the Keeler basin compare closely with taxa from that region.

Most of the conodont species present occur in both Russia and North America and indicate that dispersal of this group was uninhibited. The major difference between faunas from these three areas is the absence of Mesogondolella in the North American midcontinent, probably due to environmental factors. Thus, the conodonts are more useful than the fusulinids for correlation of the American section with the Lower Permian stratotype.

CORRELATION OF BIOSTRATIGRAPHIC AND LITHOSTRATIGRAPHIC UNITS

The stratigraphic section in the Keeler basin appears to represent essentially continuous deposition from earliest Pennsylvanian time into the Sakmarian (Early Permian), as shown by the succession of stages represented in the members of the Keeler Canyon Formation and the Lone Pine Formation. The conodont faunas represent all stages of the Pennsylvanian (except the Atokan) and Lower Permian into the Sakmarian; the fusulinid faunas represent all stages from Atokan to Sakmarian.

The stratigraphic occurrence of conodonts and fusulinids in the four measured sections presented here allows correlation and dating of the stratigraphic units within the Keeler basin (Fig. 7).

KEELER CANYON FORMATION

Tnemaha Reservoir Member

Limited data on fossils are presently available from this member of the Keeler Canyon Formation. The only collection of conodonts, from the basal beds, yielded a rich.

Figure 14. Missourian Pa elements from the Cerro Gordo Spring Member of the Keeler Canyon Formation. All specimens X60 unless otherwise noted. 1, 4, 7, Streptognathodus elegantulus Stauffer and Plummer, 1, sample U-17, BYU 2K00117; 4, juvenile from sample U-25, BYU 2K00118; 7, sample U-17, BYU 2K00119; 2, 11, 13, Idiognathodus magnificus Stauffer and Plummer, 2, juvenile from sample U-26, BYU 2K00120; 11, sample U-25, BYU 2K00121; 13, sample U-18, BYU 2K00122; 3, 8, Streptognathodus confragus (Gunnell), both from sample U-14, 3, BYU 2K00123; 8, BYU 2K00124; 5, 6, Gondolella subancileata Gunnell, both from sample U-14, 5, BYU 2K00125; 6, BYU 2K00126; 9, 15, 16, Idiognathodus sulciferus Gunnell, 9, sample U-17, BYU 2K00127; 15, sample U-13, BYU 2K00128; 16, sample U-14, BYU 2K00129; 10, Streptognathodus cancellatus (Gunnell), sample U-13, X65, BYU 2K00130; 12, Streptognathodus excelsus STAUFFER and PLUMMER, sample U-38, BYU 2K00131; 14, Idiognathodus n. sp. A of Barrick et al., 1996, sample 9756, BYU 2K00132; 17, Idiognathodus eccentricus (Ellison), sample U-12, BYU 2K00133.
fauna containing Idiognathoides convexus, I. sinuatus, and Declinognathodus (Stone, 1984). The joint occurrence of these species suggests correspondence with the upper Morrowan I. convexus Zone. The presence of the fusulinids Pseudostaffella and Fusulinella? (of Fusulinid Zone 1) higher in the section indicates that deposition continued into the Atokan.

Tihvpah Limestone Member

Zone C1 conodonts were recovered from samples of the Tihvpah Limestone Member near Quartz Spring in the Cottonwood Mountains (Fig. 2). Fusulinids from this unit form parts of Zones F1 and F2, and include Fusulinella from near Tienmah Reservoir, Fusulinella, Wedekindellina, and Beedeina from exposures near Quartz Spring, and Beedeina and Wedekindellina from the northern Santa Rosa Hills. Ross and Sabin (1965) reported a very similar assemblage from the basal beds of the Desmoinesian in southeast Arizona.

Previously the Tihvpah Limestone Member was considered entirely Atokan in age (Merriam and Hall, 1957; McAllister, 1952) based on the presence of Fusulinella. New collections suggest, however, that deposition of the Tihvpah Limestone began in the upper part of the Atokan and extended into the Desmoinesian.

Cerro Gordo Spring Member

Conodonts have been recovered from this member in both the Cerro Gordo region and the Ubehebe Mine Section. Specimens representing Conodont Zone C2, corresponding with the late Desmoinesian Idiognathodus n. nodocarinatus Zone, occur in Cerro Gordo Section 1 (samples 149A, 360A, and 680A) and several samples from the lower part of the member 4.1 km northwest of Cerro Gordo.

Sample 975A from Section 1 represents Zone C3. Fifteen samples from the Cerro Gordo Spring Member in the Ubehebe Mine section produced conodonts showing that this member ranges from late Desmoinesian to early Gazelian in age. The lowest four samples (U-5A through U-11) are dominated by Pa elements of Idiognathodus nodocarinatus of Zone C2. Sample U-12 higher in the section is characterized by conodonts of Zone C3. Slightly higher in the section (samples U-13, U-14), Zone C4, represented by S. confragus, appears. Four higher samples (U-17 to U-26) belong to Zone C5. The uppermost sample from the Cerro Gordo Spring Member (U-34.5) yielded Zone C6 conodonts.

In contrast to the conodont faunas, the fusulinid faunas are sparse in the Cerro Gordo Spring Member. Several species of Beedeina and a species of Wedekindellina from Section 1 represent Zone F2 and demonstrate a Desmoinesian age as also shown by the conodont collections. The single fusulinid collection representing the Missourian Zone F3 (S-0658) is from the upper part of the Cerro Gordo Spring Member near its type section.

Salt Tram Member (lower part)

Conodonts are moderately abundant in the coarse-grained turbidites of the lower part of the Salt Tram Member near Ubehebe Mine and in all three sections in the Cerro Gordo area. At Ubehebe Mine the lower part of the member (samples U-34.5 to U-42.5) contains Zone C6 conodonts. A fauna from the overlying beds (sample U-45) contains conodonts of Zone C7.

In section 3 near Cerro Gordo, samples S-1752, S-1794, and S-1795 contain elements of Zone C6. Sample CG-0 from Section 2 contains Zone C6 Pa elements and samples CG-490 and S-1788 higher in the section represent Zone C7. Samples U-63' and U-64' have yielded conodonts provisionally placed in Zone C8.

The lower part of the Salt Tram Member contains considerable numbers of fusulinids, mostly in the Cerro Gordo area, here grouped into Fusulinid zones F4–F6. Thus, we interpret the lower part of the Salt Tram Member to span the Gazelian-Asselian boundary. Several fusulinid samples from the Salt Tram Member in the Conglomerate...
Mesa area are assigned to zones F5 and F6 and are interpreted as correlative with the middle and upper parts of this subunit.

Salt Tram Member (upper part)

Numerous conodont faunas from the upper part of the Salt Tram Member were obtained from the Cerro Gordo Mine Sections 1 and 2. At Section 1, five productive beds spanning the entire upper Salt Tram Member were collected. The lowest fauna (sample 99-I-609) contains Zone C8 elements. Somewhat higher in the section, the unusual fauna in sample 765 noted earlier is considered to mark the top of the Asselian. Samples 492 and 97-I-902 near the top of the Salt Tram Member contain Zone C9 conodonts including *Swettognathus merrilli*.

Five beds in the lower half of the upper Salt Tram Member were also productive at Section 2. These contain Zone C8 species. Two samples from the upper half of the upper Salt Tram Member, including one from the top of the member, yielded specimens of elongate, unornamented streptognathodontids of uncertain taxonomic affinity and age. These specimens assign an as yet unnamed species belonging to the upper fauna of unornamented *Streptognathodus* (Fig. 8).

Fusulind faunas grouped into Zones F7–F9 are abundant in the upper part of the Salt Tram Member, which spans the Asselian-Sakmarian boundary. The highest fusulinid sample from the Salt Tram Member in the Conglomerate Mesa area (79-CM-84) is assigned to Zone F7 and therefore is interpreted as correlative with the lower part of this subunit.

Undivided Cerro Gordo Spring and Salt Tram Members at San Lucas Canyon

Four conodont samples and one fusulinid sample from the upper part of the Keefer Canyon Formation at San Lucas Canyon were examined. The conodont samples, which range from 30 to 625 m below the top of the formation, all contain *Streptognathodus pauchuskaensis*, and the fusulinid sample (S-1746, about 360 m below the top) contains *Trityites pinguis*. Together these fossils indicate a Gzhelian age probably including parts of conodont Zones C5 and C7. Thus, these rocks are approximately equivalent to the lower and middle parts of the lower Salt Tram Member. Conodonts from the unconformably overlying unit 7 of the sedimentary rocks of Santa Rosa Flat (sample 98-I-921) include *Swettognathus whitei* indicative of an Early Permian (Artinskian) age, which is compatible with the latest Wolfcampian age determined for this unit in the Conglomerate Mesa area by Magginetti et al. (1988) on the basis of fusulinids.

**LONE PINE FORMATION**

The Lone Pine Formation is represented by sparse conodont faunas obtained from the uppermost portion of the preserved section at Section 1, from two spot localities in the vicinity of the Cerro Gordo Mine, and two horizons at Ubehebe Mine. The Lone Pine faunas, along with those in the uppermost part of the Salt Tram Member, are assigned to Zone C9, which is correlated with the *Swettognatus merrilli* conodont zone. An early Sakmarian age is indicated. Fusulinid Zone F10 from the lower part of the Lone Pine Formation corresponds with the upper part of Conodont Zone C9. This fauna is rather poor. The presence of *Schwagerina* cf. *S. bellula*, however, is consistent with the early Sakmarian age suggested by the conodonts.

**GEOLOGIC HISTORY OF THE KEELER BASIN**

The Keefer basin is defined by the regional distribution of the deep-water Keefer Canyon Formation and member A of the Lone Pine Formation. In the northern and central parts of the basin the Keefer Canyon Formation overlies older basinal strata of the Chesterian (Upper Mississippian) Rest Spring Shale, which in turn overlies the deep-water Mississippian Kearsarge and Mexican Spring Formations.
of early Late Mississippian (Meramecian) age (Stevens et al., 1996). Thus, this part of the Keeler basin originated in the Mississippian and probably was a southwestern extension of the Antler foreland basin of central Nevada (Poole and Sandberg, 1991). In Nevada, however, the Antler foreland basin rocks generally pass upward into shallow-water carbonate rocks of Pennsylvania age in contrast to east-central California where deep-water sedimentation continued through the Pennsylvania and into Early Permian time, evidently reflecting continued subsidence of this part of the basin.

We consider the Keeler basin to have originated when the western margin of the North American continent was truncated (Stone and Stevens, 1988). This event resulted in a change in trend of facies belts in east-central California from southwestward, with depositional belts representing progressively deeper water to the west, to southeastward. South of about the latitude of Lone Pine, part of the older shelf was down-dropped, resulting in deposition of the deep-water Keeler Canyon Formation above Late Mississippian shallow-shelf rocks. The change in trend of the Keeler basin in this region (Fig. 1) reflects these events.

Throughout its early history (Morrowan through most of the Desmoinesian) the Keeler basin accumulated mostly fine-grained limestone, probably deposited in moderately deep water. The major exception is in the Tinemaha Reservoir area where a thick, but very local turbidite sequence (Tinemaha Reservoir Member) was deposited. Thin sequences of coeval fine-grained calcareous rocks were deposited locally elsewhere. Abundant quartz sand and silt associated with the limestone turbidites near Tinemaha Reservoir suggest that their source was somewhere on the Bird Spring shelf rather than from the closer Mount Baldwin platform, the limestones of which are quartz free (Stevens and Greene, 1999).

During the latter part of the Atokan and early Desmoinesian time, a thin sequence of cherty micritic limestone of the Tihiviah Limestone Member was deposited throughout most if not all of the Keeler basin. The rate of sediment accumulation evidently continued to be very slow. The Tihiviah Limestone is not a turbidite sequence although debris-flow deposits composed of coarse-grained carbonate detritus derived from shallow water occur locally. This unit probably represents deposition in relatively deep, quiet water.

Limestone turbidites and calcareous siltstone of the Cerro Gordo Spring Member represent the first widely distributed turbidite sequence in the Keeler basin. This member accumulated from Desmoinesian into early Czhelian time. These strata reflect deposition in relatively deep water downslope from the adjacent Bird Spring carbonate shelf. Yose (1987) and Yose and Heller (1989) interpreted the Cerro Gordo Spring Member as a basin-margin sequence that accumulated as a line-sourced debris apron. Rates of sediment accumulation apparently increased in the late Desmoinesian, decreased greatly in the early and middle Missourian, and increased again in the late Missourian and early Czhelian.

The thick sequence of silty to sandy limestone turbidites that comprise the Salt Tram Member of the Keeler Canyon Formation accumulated from Czhelian into Sakmarian time. This member has been interpreted both as a submarine fan sequence (Parker, 1976; Stone, 1984) and as a debris apron sequence (Flora, 1984; R.P. Miller, 1989) derived from the Bird Spring carbonate shelf. Regardless, the Salt Tram Member clearly reflects an extended episode of deposition during which mixed carbonate and terrigenous sediment gravity flows carried shallow-water material downslope into the Keeler basin. Paleocurrent data from this member indicate southward flow in the Ubehebe Mine area and southwestward flow in the Cerro Gordo area. The rate of sediment accumulation was high throughout middle Czhelian to middle Sakmarian time.

The origin of the turbidites in which the fusulinids and conodonts occur is not precisely known. In the upper part of the Asselian and in the Sakmarian a number of endemic species not known from nearby platform rocks are present. Paleocurrent measurements (Stevens et al., 1979; Parker, 1976; Stone, 1984; Flora, 1984) show transport to the south at Ubehebe Mine and southwest in the southern Inyo Mountains. The only possible source rocks of the appropriate age to the northeast are limestones of the Tippipah Limestone on the Nevada Test Site, more than 100 km away. The top of section there, however, is only as
young as early Asselian (VI. Davydov, oral commun., 1999), so comparison of most Permian faunas is impossible. The Gzhelian and early Asselian fusulinids at the Nevada Test Site, however, are not closely similar to those in the Keeler basin (C.H. Stevens, unpub. data), so these shelf limestones apparently were not the source of the Keeler Canyon turbidites. Apparently the carbonate shelf that gave rise to the turbidites in the upper part of the Keeler Canyon Formation is not now exposed.

Following deposition of the Salt Tram Member the Keeler basin evidently was largely cut off from its source of limestone turbidites, and the predominantly fine-grained strata of member A of the Lone Pine Formation accumulated in a basin-plain environment. During this time up to about 1000 m of very fine, siliciclastic sediment of member A of the Lone Pine Formation was deposited in the south-central Inyo Mountains. This change in sediment type and rate of accumulation may have been related to development of the Last Chance thrust that eventually resulted in emplacement of the Keeler Canyon Formation against the older Mississippian shelf margin to the east (Stevens and Stone, in press), marking the end of the Keeler basin depositional sequence. We interpret the faulted contact that characterizes the base of the Keeler Canyon Formation throughout the region as part of the Last Chance thrust.

After thrusting, shallow-marine carbonate rocks of unit 7 of the sedimentary rocks of Santa Rosa Flat overlapped the uplifted Keeler Canyon Formation in the Conglomerate Mesa and San Lucas Canyon areas. In contrast, deep-water sedimentation continued in the western part of the former Keeler basin, resulting in deposition of member B of the Lone Pine Formation. Shelf limestones of unit 7 and the overlying unit 8 are correlative with the limestone turbidites of member B and may have been their source (Stone et al., 2000).

SUMMARY AND TECTONIC SIGNIFICANCE

The limestone-rich Keeler Canyon Formation, here divided into four formal members, and the lower part of the dominantly siliciclastic Lone Pine Formation were deposited in a basin close to the late Paleozoic continental margin in east-central California from the Morrowan (Early Pennsylvanian) to Sakmarian (Early Permian) time. This basin, here called the Keeler basin, cut across earlier facies belts, probably the result of an earlier continental truncation to the west. Deposition was terminated by an orogenic event that resulted in development of the Last Chance thrust in the latest Sakmarian.

Strata of the Keeler basin contain numerous fusulinid and conodont faunas, most of which were deposited by sediment-gravity flows that probably originated at the margin of the Bird Spring carbonate platform to the northeast. The fusulinid faunas are composed of taxa with North American affinities, with endemic constituents, and with elements of the McCloud Limestone of northwestern California. The conodonts are closely similar to species in the Ural Mountains of Russia and Kazakhstan, as well as midcontinent USA.

The Keeler basin was one of a succession of sedimentary basins that developed along the continental margin during the latter part of the Paleozoic in east-central California (Stone and Stevens, 1988). The history of this basin reflects initial subsidence and subsequent compressional uplift along the margin following its truncation, probably by transcurrent faulting, in early Pennsylvanian time. This structural event was followed by a series of events involving basin subsidence and subsequent uplift in later Early Permian to earliest Triassic time (Stevens et al., 1998). This structural history apparently reflects a protracted period of tectonic instability and variability as the continental margin changed from the dominantly passive margin that had characterized most of the Paleozoic to the active, convergent margin that would become fully developed by the Late Triassic and continue through the remainder of the Mesozoic.

APPENDIX 1: MEASURED SECTIONS

Sections in Cerro Gordo Mine area

Note: All sections are in the Cerro Gordo Peak 7.5’ quadrangle.

Section 1. Measured on slopes and ridges northwest of Cerro Gordo Road by C.H. Stevens and Jerry Lewis in 1964; reexamined by C.H. Stevens and Paul Stone in 1999. Base of section is 1 km northwest of road at elev. 8240 ft; top of section is 2.5 km northwest of road at elev. 6820 ft. Base of section is reached by a jeep road leading northwest from Cerro Gordo Mine. Section extends from base of Keeler Canyon Formation, which is faulted against Rest Spring Shale, to top of Lone Pine Formation, which is unconformably overlain by Union Wash Formation. Unit thicknesses: Cerro Gordo Spring Member of Keeler Canyon Formation, 428 m; Salt Tram Member of Keeler Canyon Formation, 833 m (lower part, 516 m; upper part, 317 m); Lone Pine Formation, 67 m.

Section 2. Measured along south side of Cerro Gordo Road by S.M. Ritter in 1991; reexamined by S.M. Ritter, C.H. Stevens, and Paul Stone in 1999. Base of section is adjacent to road at elev. 7040 ft; top of section is adjacent to road at elev. 6520 ft. Section extends from base of Salt Tram Member of Keeler Canyon Formation to top of Lone
Pine Formation, which is unconformably overlain by Union Wash Formation. Unit thicknesses: Salt Tram Member of Keeler Canyon Formation, 643 m (lower part, 387 m; upper part, 255 m); Lone Pine Formation, 22 m. In canyon 0.3 km northwest of measured section, Lone Pine Formation is 63 m thick, the upper 30 m of which consists of limestone that is truncated by unconformity with Union Wash Formation between here and Cerro Gordo Road. About 0.1 km south of measured section, Lone Pine Formation is truncated by unconformity with Union Wash Formation.

Section 3. Measured in canyon east of Estelle Tunnel by Riggs (1962); reexamined by C.H. Stevens, Paul Stone, and S.M. Ritter in 1999. Base of section is 1 km east-northeast of Estelle Tunnel at elev. 7080 ft; top of section is adjacent to Estelle Tunnel at elev. 6100 ft. Section extends from within Cerro Gordo Spring Member of Keeler Canyon Formation to top of Keeler Canyon Formation, which is unconformably overlain by Union Wash Formation. Unit thicknesses: Cerro Gordo Spring Member of Keeler Canyon Formation, 87 m (partial thickness); Salt Tram Member of Keeler Canyon Formation, 549 m (lower part, 330 m; upper part, 219 m). Note: Base of section is about 0.4 km farther up the canyon from Estelle Tunnel and 500 ft higher in elevation than shown on the location map of Riggs (1962, fig. 4).

Ubehebe Mine section

Measured in canyon west of Ubehebe Mine by Stone (1984). Base of section is 2.3 km west-northwest of Ubehebe Mine, elev. 3360 ft, in the Teakettle Junction 7.5° quadrangle; top of section is 3.75 km west-southwest of Ubehebe Mine, elev. 2680 ft, in the Ubehebe Peak 7.5° quadrangle. Section extends from base of Keeler Canyon Formation, which is faulted against the Rest Spring Shale, into the Lone Pine Formation. Unit thicknesses: Cerro Gordo Spring Member of Keeler Canyon Formation, 232 m; Salt Tram Member of Keeler Canyon Formation, 829 m; Lone Pine Formation, 182 m (partial thickness). Top of section is at synclinal fold hinge. Approximately 1.5 km to the south, lower shaly subunit of Lone Pine Formation is about 300 m thick and is conformably overlain by upper limestone subunit which has a maximum exposed thickness of about 150 m in core of large syncline.

APPENDIX 2: FOSSIL LOCALITIES

Note: Fusulinid and conodont taxa identified at each locality are listed. Fusulinid zone (F1–10) and/or conodont zone (C1–9) are indicated at end of each listing.

Measured section 1,
Cerro Gordo Mine area

Keeler Canyon Formation, Cerro Gordo Spring Member:

149 45 m (149 ft) above base of section. Fusulinids: Beedeina aff. B. howorthi, B. aff. B. occultifons. (F2)
149A Approximately same locality as 149. Conodonts: Idiognathodus nodocarnatus, I. expansus, I. obliquus, Gondolella magna. (C2)
360 110 m (360 ft) above base of section. Fusulinids: Wedekindellina sp. 1. (F2)
360A Approximately same locality as 360. Conodonts: Idiognathodus obliquus, I. expansus. (C2)
680A Approximately 207 m (680 ft) above base of section. Conodonts: Gondolella magna, Idiognathodus expansus (C2)
975A Approximately 297 m (975 ft) above base of section. Conodonts: Idiognathodus n. sp. A of Barrick et al. (1996). (C3)

Keeler Canyon Formation, Salt Tram Member, lower part:

1850 852 m (2795 ft) above base of section. Fusulinids: Pseudofusulinella sp., Schwagerina sp. (F6)
2035 803 m (2634 ft) above base of section. Fusulinids: Trictites aff. T. ventricosus var. sacramentensis, T. sp. 3°, Schwagerina aculeata, S. modica. (F6)
2282 738 m (2422 feet) above base of section. Fusulinids: Trictites cellamagnus, Schwagerina sp. (F5)
2292 736 m (2415 ft) above base of section. Fusulinids: Trictites aff. T. beedei, T. pinguis, T. sp. 3, Schwagerina sp. (F5)
2665 641 m (2104 ft) above base of section. Fusulinids: Trictites hermanni?, T. pinguis, T. sp. 2, Pseudofusulinella sp. (F5)
2785 611 m (2005 ft) above base of section. Fusulinids: Trictites californicus?, T. hermanni, T. sp. 2 (F4)
3115 532 m (1587 ft) above base of section. Fusulinids: Trictites aff. T. hobbensis. (F4)
S-1778 Same locality as 3549. Fusulinids: Trictites pinguis, T. cf. T. hermanni. (F4)

Keeler Canyon Formation, Salt Tram Member, upper part:

492 1226 m (3957 ft) above base of section. Fusulinids: Reticulosepta sp. 1, R.? sp., 4, R. sp. 6, R.? sp. 7, Schwagerina aff. S. arta, S. turgida, S. sp. 1, Pseudofusulinella sp., Pseudosch-
wagnerina sp., Eoparafusulina? sp., Stewartina sp. 3. Conodonts: Sweetognathus merrilli. (F9, C8)

765 1136 m (3726 ft) above base of section. Fusulinids: Schwagerina turgida, Reticulocepta? sp. 4, Stewartina sp. 1. Conodonts: Wardlawella expansa, Streptognathodus fuchengensis, S. spp.; and transitional form between W. adenticulata and Sweetognathus merrilli. (F9, C8)

(F9, C8)

867 1110 m (3642 ft) above base of section. Fusulinids: Pseudo fusulinella sp., Eoparafusulina aff. E. gracilis. (F8)

1090 1054 m (3458 ft) above base of section. Fusulinids: Reticulocepta? sp. 6, R.? sp. 7, Eoparafusulina? sp. (F8)


1418 968 m (3175 ft) above base of section. Fusulinids: Pseudofusulinella sp., Triticites aff. T. ventricosus sacramentensis, Schwagerina dumensis. (F7)

1471 955 m (3131 ft) above base of section. Fusulinids: Triticites sp., Pseudoschwagerina aff. P. rhodesi, Schwagerina dumensis, S. sp. 3. (F7)


S-1768 Same locality as 492. Fusulinids: Reticulocepta? sp. 7. (F9)

97-I-901 Top of uppermost bed in Keeler Canyon Formation, 1261 m (4138 ft) above base of section. Conodonts: Sweetognathus merrilli. (C9)

99-I-609 Approximately same locality as 1471. Conodonts: Streptognathodus fusus, Mesogondolella belladontae, Wardlawella expansa. (C8)

99-I-610 73 m (240 ft) above 99-I-609, approximately 1028 m (3371 ft) above base of section. Conodonts: Mesogondolella dentiseparata, Streptognathodus longissimus. (C8)

Lone Pine Formation:

91 1305 m (4281 ft) above base of section. Fusulinids: Pseudofusulinella sp., Triticites sp. (reworked), Cuniculina? sp., Schwagerina turgida?, S. sp. 2, Reticulocepta sp., Stewartina sp. 2. (F10)

97-I-901 10.5 m (34 ft) below top of section. Conodonts: Streptognathodus n. sp. 1, S. n. sp. 2. (C9)


Measured section 2, Cerro Gordo Mine area

Keeler Canyon Formation, Salt Tram Member, lower part:

CG-0 Base of section. Conodonts: Streptognathodus pawhuskaensis, S. viridulus. (C6)

CG-490 149 m (490 ft) above base of section. Conodonts: Idiognathodus magnificus, Streptognathodus pawhuskaensis, S. costaeplabellus. (C7)

S-1749 322 m (1055 ft) above base of section. Fusulinids: Triticites cellamagnus, T. sp. 3. (F6)

S-1753 Same locality as CG-490. Fusulinids: Triticites aff. T. kelleyensis, T. confertoides?, Pseudo- fusulinella sp. 1. (F5)

S-1759 285 m (935 ft) above base of section. Fusulinids: Pseudofusulinella sp. 1, Triticites meeki, T. sp. 3, Reticulocepta? sp. 3. (F6)

S-1764 99 m (325 ft) above base of section. Fusulinids: Triticites burgessae? (F5)

S-1765 288 m (945 ft) above base of section. Fusulinids: Triticites aff. T. directus?, T. aff. T. holbliensis? (F6)

S-1788 Ridge southeast of measured section approximately 198 m (650 ft) above base of section. Conodonts: Streptognathodus pawhuskaensis. (C7)

Keeler Canyon Formation, Salt Tram Member, upper part:

CG-1355 413 m (1355 ft) above base of section. Conodonts: Streptognathodus aff. S. barskovi. (C8)

CG-1376 420 m (1376 ft) above base of section. Conodonts: Streptognathodus constrictus (primitive). (C8)

CG-1521 464 m (1521 ft) above base of section. Conodonts: Streptognathodus fusus, S. fuchengensis, S. longissimus, Mesogondolella dentiseparata. (C8)

CG-1550 473 m (1550 ft) above base of section. Conodonts: Streptognathodus aff. S. cristellaris, Mesogondolella belladontae. (C8)

CG-1570 479 m (1570 ft) above base of section. Conodonts: Streptognathodus longissimus, Mesogondolella sp. (C8)
CG-1920 585 m (1920 ft) above base of section. Conodonts: *Streptognathodus* spp. (C8)


S-1756 Same locality as CG-1570. Fusulinids: *Reticulosepta* sp. 6, *Schwagerina* aff. *S. andrensenis*, S. aff. *S. subletensis*, S. sp. 3. (F8)

S-1757 Same locality as CG-1550. Fusulinids: *Reticulosepta* sp. 6?, *Schwagerina* sp. 3. (F8)

S-1767 Base of upper bed in Keeler Canyon Formation, 640 m (2098 ft) above base of section. Fusulinids: *Pseudeustinus* sp., *Reticulosepta* sp. 6, R.? sp. 7, *Schwagerina turgida*, S. sp. 1, *Pseudeustinus decorus*. (F9)

S-1787 Ridge southeast of measured section approximately 387 m (1270 ft) above base of section. Conodonts: *Streptognathodus fuscus*. (C8).


S-1787 Ridge southeast of measured section approximately 387 m (1270 ft) above base of section. Conodonts: *Streptognathodus* aff. *S. postfusus*. (C8)

Measured section 3, Cerro Gordo Mine area

Keeler Canyon Formation, Salt Tram Member, lower part:


S-1758 Approximately 415 m (1360 ft) above base of section, near locality C-50A of Rigs (1962); just below base of upper part of Salt Tram Member. Fusulinids: *Trinitites cellamagnus*, *Schwagerina* sp. 3. (F6)

S-1770 302 m (990 ft) above base of section, same locality as C-67 of Rigs (1962). Fusulinids: *Trinitites confertoides*, T. sp. 3, T.? sp. 4, *Reticulosepta* sp. (F5)

S-1794 297 m (975 ft) above base of section, same locality as C-69 of Rigs (1962). Conodonts: *Streptognathodus brownillensis*, S. aff. *S. longilatus*, *S. virgicus*. (C7)

S-1795 348 m (1141 ft) above base of section. Conodonts: *Streptognathodus* n. sp. A of Chernykh and Ritter (1997). (C7)

S-1796 Approximately 361 m (1185 ft) above base of section, 13.5 m above red debris-flow deposit. Conodonts: *Streptognathodus* spp. (C7)

Keeler Canyon Formation, Salt Tram Member, upper part:


S-1780 Same locality as S-1751. Fusulinids: *Reticulosepta* sp. 2, R.? sp. 3, R.? sp. 6, *Schwagerina* sp. (F9)

Ubehebe Mine section

Keeler Canyon Formation, Cerro Gordo Spring Member:

U-5A 11 m (36 ft) above base of section. Conodont: *Idiognathodus obliquus*. (C2)

U-7 16 m (59 ft) above base of section. Conodonts: *Idiognathodus expansus*, *I. obliquus*, *Gondolella magna*. (C2)

U-9 20 m (66 ft) above base of section. Conodonts: *Neognathodus medadulittus*. (C2)

U-11 28 m (92 ft) above base of section. Conodonts: *Idiognathodus obliquus*, *I. expansus* (gerontic). (C2)

U-12 30 m (98 ft) above base of section. Conodonts: *Idiognathodus sulciferus*, *I. eccentricus*, *I. expansus*. (C3)


U-14 48 m (157 ft) above base of section. Conodonts: *Idiognathodus sulciferus*, *Streptognathodus confragus*, *Gondolella sublaceolata*. (C4)

U-17 61 m (200 ft) above base of section. Conodonts: *Idiognathodus magnificus*, *Streptognathodus excelsus*, *S. elegantulus*. (C5)

U-18 68 m (223 ft) above base of section. Conodonts: *Idiognathodus magnificus*, reworked *Idiognathoides* sp., *Gondolella* sp. (C5)

U-25 115 m (377 ft) above base of section. Conodonts: *Streptognathodus excelsus*, *S. elegantulus*, *Idiognathodus magnificus*. (C5)

U-26 119 m (390 ft) above base of section. Conodonts: *Streptognathodus excelsus*, *S. elegantulus*, *I. magnificus*. (C5)

U-31 137 m (450 ft) above base of section. *Idiognathodus* sp., *Neognathodus boothrys* (reworked). (C5)
Keeler Canyon Formation, Salt Tram Member:

Conodonts: *Streptognathodus pachuskaensis*, *S. excelsus*. (C6)  

**U-34.5**  197 m (646 ft) above base of section. Conodonts: *Streptognathodus pachuskaensis*, *S. excelsus*. (C6)

**S-1772**  Salt Tram Member, upper part, 5 m below top, about 0.3 km northwest of measured section 2 and Cerro Gordo Road, near floor of wash at elev. 6560 ft. Fusulinids: *Reticulosepta* sp. 5, *R.?* sp. 6, *Schwagerina* aff. *S. andresensis*?. (F9)

**U-36**  233 m (764 ft) above base of section. Conodonts: *Streptognathodus pachuskaensis*, *S. excelsus*. (C6)

**S-1773**  Cerro Gordo Spring Member, imprecisely located along line of measured section 1. Fusulinids: *Beedeina* aff. *B. acme*. (F2)

**U-38**  280 m (918 feet) above base of section. Fusulinids: *Trititcos aff. T. kelleyensis*, *T. sp. 3*. (F4)

**S-1774**  Same locality as 82-I-24; field loc. 99-I-1022. Fusulinids: *Reticulosepta?* sp. 6, *R.?* sp. 7, *Schwagerina* aff. *S. subletensis*, *Eoparafusulina*? sp. (F9)

**U-42.5**  344 m (1128 ft) above base of section. Conodonts: *Streptognathodus pachuskaensis*. (C6)

**S-1775**  Same locality as 82-I-23; field loc. 99-I-1021. Fusulinids: *Pseudofusulina* sp., *Schwagerina* aff. *S. subletensis*?. (F9)

**U-45**  390 m (1279 ft) above base of section. Conodonts: *Streptognathodus tenuiauleus*, *S. costaeolabellus*, *Palmozellepis* sp. (reworked). (C7)

**S-1777**  Salt Tram Member, upper part, about 10 m below S-1774; probably same stratigraphic level as sample 765 in measured section 1; field loc. 99-I-1023. Fusulinids: *Schwagerina* aff. *S. subletensis*, *Pseudoschwagerina* aff. *P. parabeast*. (F9)

**U-46**  418 m (1371 ft) above base of section. Fusulinids: *Trititcos pinguis*. (F5)

**U-47**  445 m (1459 feet) above base of section. Fusulinids: *Trititcos bellamagnus*. (F5)

**U-54**  631 m (2070 ft) above base of section. Conodonts: *Streptognathodus tenuiauleus*, *S. virgilicus* (reworked). (C7)

**U-48**  708 m (2322 ft) above base of section. Conodonts: *Diplognathodus* sp., narrow *Strepognathodus*. (C7)

**S-1779**  Salt Tram Member, about 40 m below top; downhill to west from 82-I-24 at about elev. 7400 ft; probably same stratigraphic level as sample 492 in measured section 1. Fusulinids: *Pseudofusulina purpura*, *Chusenella* cf. *C. j stressfulia*, *Eoparafusulina* sp. 1, *Schwagerina* aff. *S. subletensis*?, *S. modica*. (F9)

**U-57**  722 m (2368 ft) above base of section. Fusulinids: *Schwagerina modica*?, *S. aculeata*. Conodonts: Reworked *ioriodus* sp. (F6, C8)

**U-54**  732 m (2404 ft) above base of section. Fusulinids: *Schwagerina aculeata*? Conodonts: *Streptognathodus* sp. (F6, C8)

**U-61**  788 m (2588 ft) above base of section. Conodonts: *Diplognathodus* sp., narrow *Streptognathodus*. (C7)

**U-63**  798 m (2618 ft) above base of section. Fusulinids: *Schwagerina modica*?, *S. aculeata*. Conodonts: Reworked *ioriodus* sp. (F6, C8)

**U-64**  818 m (2685 ft) above base of section. Fusulinids: *Schwagerina culeata*? Conodonts: *Streptognathodus* sp. (F6, C8)

Lone Pine Formation, upper Limestone subunit (1.5 km south of measured section):

**U-94**  Near base of subunit. Conodonts: *Streptognathodus* n. sp., 1, *Mesogondoellella lata*, *Aedognathodus paralatus*. (C9)

**S-1780**  Cerro Gordo Spring Member, about 30 m above base, in canyon 0.7 km N.65°E. of hill 7664 at elev. 7840 ft, about 4.1 km northwest of Cerro Gordo Mine. Conodonts: *Idiognathodus nodocarinatus*, *Neognathodus medusilimus*, *Conodolella magna*. (C2)

**U-95**  Near base of subunit. Conodonts: *Streptognathodus pachuskaensis* (reworked)?, (C9)

**S-1781**  Cerro Gordo Spring Member, very close to 82-I-28. Conodonts: *Idiognathodus expansus*. (C2)

**U-96**  Near top of subunit. Fusulinids: *Pseudofusulina decora?*, *Trifititcos pinguis* (reworked), *Reticulosepta* sp. 6?, *Schwagerina* cf. *S. bellula*?, *S. sp. 2*. (F10)

**82-I-28**  Cerro Gordo Spring Member, about 130 m below top, near crest of hill at elev. 7520 ft, 0.5 km S.50°W. of hill 7664, about 4.5 km northwest of Cerro Gordo Mine, north across canyon from measured section 1. Fusulinids: *Trititcos* sp., *Reticulosepta?* sp. 3. Conodonts: *Streptognathodus* sp., *Mesogondoellella dentiseparea*. (F9, C8)

**S-1782**  Cerro Gordo Spring Member, 1 m above base, down section from 82-I-28 and 29, 0.8 km N.65°E. of hill 7664 at elev. 7880 ft. Conodonts: *Neognathodus bothrops*, *Idiognathodus expansus*. (C2)

**U-97**  82-I-29  Cerro Gordo Spring Member, 2 m above base, 1 km S.75°E. of Morning Star Mine at

Note: All localities are in Cerro Gordo Peak 7.5' quadrangle.

Keeler Canyon Formation:

**82-I-30**  Cerro Gordo Spring Member, 1 m above base, down section from 82-I-28 and 29, 0.8 km N.65°E. of hill 7664 at elev. 7880 ft. Conodonts: *Neognathodus bothrops*, *Idiognathodus expansus*. (C2)

**S-0858**  Upper part of Cerro Gordo Spring Member, west of Cerro Gordo Road. Fusulinids: *Trifititcos burgessae*. (F3)

**82-I-31**  Cerro Gordo Spring Member, 2 m above base, 1 km S.75°E. of Morning Star Mine at
Lone Pine Formation:

S-1760 Upper limestone unit, near northern end of exposure, 0.5 km S.80°W. of hill 7294 at elev. 6900 ft, about 2 km northwest of measured section 2 and Cerro Gordo Road. Fusulinids: *Pseudoschwagerina*? sp., *Pseudofusulina decorata*. (F10)

99-I-608 Same locality as S-1760. Conodonts: *Swee
tognathus merrilli*, *Mesogondolella lata*. (C9)

99-I-613 Upper limestone subunit, near top, about 0.3 km northwest of Cerro Gordo Road at elev. 6600 ft. Conodonts: *Mesogondolella lata*, *Sweetognathus merrilli*. (C9)

Spot localities, Conglomerate Mesa area

S-0613 Keeler Canyon Formation, uppermost part, near S-0614. Fusulinids: *Triticina*? sp. 4. (F6)

S-0614 Keeler Canyon Formation, uppermost part, beneath unit 7 of sedimentary rocks of Santa Rosa Flat north of Conglomerate Mesa, on ridge north of hills 7236 and 7231 at about elev. 7000 ft, Nelson Range 7.5° quadrangle. Fusulinids: *Triticina confertoides*, T. sp. 3. (F6)

S-1371 Keeler Canyon Formation, lowest fusulinid-bearing bed observed, northern Santa Rosa Hills east of Conglomerate Mesa, 0.25 km N.60°W of hill 6724 at about elev. 6400 ft, Nelson Range 7.5° quadrangle. Fusulinids: *Triticina aff. T. beedei*. (F5)


S-1747 Keeler Canyon Formation, upper part, on same ridge as 79-CM-84 and about 100 m stratigraphically lower, 150 m west of hill 7315; field loc. 79-CM-85. Fusulinids: *Pseudofusulina* sp. 1, *Triticina pinguis* (reworked), *Reticulosepta*? sp., *Schwagerina dunnensis*?, S. sp. 1. (F77)

79-CM-84 Keeler Canyon Formation, uppermost part, about 50 m below contact with unit 7 of sedimentary rocks of Santa Rosa Flat north of Conglomerate Mesa, on ridge just west and below summit of hill 7315, Nelson Range 7.5° quadrangle. Fusulinids: *Pseudofusulina simplex*, *Triticina meeki*, T. sp. 1, *Pseudo-
schwagerina* cf. *P. needhami*, *Schwagerina* sp. 1?. (F7)

79-CM-86 Keeler Canyon Formation, upper part, on same ridge as S-1747 and about 100–200 m stratigraphically lower, 0.3 km west of hill 7315. Fusulinids: *Triticina* sp. 3. Conodonts: *Streptognathodus pachuskaensis* (probably reworked). (F6)

79-CM-88 Keeler Canyon Formation, uppermost part, 15 m below contact with Leonardian-age limestone of sedimentary rocks of Santa Rosa Flat, on northeast side of ridge 0.75 km east of hill 7602 at elev. 7080 ft near southeast corner of Cerro Gordo Peak 7.5° quadrangle. Conodonts: *Streptognathodus pachuskaensis* (probably reworked). Conodont zone uncertain.

Spot localities, San Lucas Canyon area

Note: Localities are in a side canyon draining into San Lucas Canyon from the east. Side canyon begins at a sharp bend in San Lucas Canyon 0.4 km S.75°E. of hill 5607, Nelson Range 7.5° quadrangle. Keeler Canyon Formation in this area has an estimated thickness of 1040 m and is overlain by Permian limestone interpreted to represent unit 7 of the sedimentary rocks of Santa Rosa Flat, which crops out in one small area near the head of the side canyon 0.25 km S.60°W of hill 6121.

98-I-921 Unit 7, sedimentary rocks of Santa Rosa Flat. Conodonts: *Swee
tognathus whitei*. (higher than C9)

98-I-922 Keeler Canyon Formation, about 30 m below top. Conodonts: *Streptognathodus pachuskaensis*. (C77)

98-I-926 Keeler Canyon Formation, about 520 m below top. Conodonts: *Streptognathodus pachuskaensis*. (C6)

98-I-927 Keeler Canyon Formation, about 610 m below top. Conodonts: *Streptognathodus pachuskaensis*. (C6)

98-I-928 Keeler Canyon Formation, about 625 m below top. Conodonts: *Streptognathodus pachuskaensis*, *S. virguliculus*. (C6)

S-1746 Keeler Canyon Formation, about 360 m below top. Fusulinids: *Triticina pinguis*. (F5)
Spot localities, Tinemaha Reservoir area

S-1208 Keeler Canyon Formation, upper part of exposed section (Thivipah Limestone Member), on ridge about 3 km S. 80° E. of southeast corner of Tinemaha Reservoir. Tinemaha Reservoir 7.5’ quadrangle. Fusulinids: Pseudostaffella sp., Fusulinella fugax. (F1)

S-1225 Keeler Canyon Formation, Tinemaha Reservoir Member, lower part, same ridge as S-1208. Fusulinids: Fusulinella sp., Pseudostaffella cf. P. powwouensis. (F1)


Spot localities, Quartz Spring area

Note: All samples are from Thivipah Limestone Member of Keeler Canyon Formation which forms several isolated exposures that overlie Rest Spring Shale on probable low-angle fault contacts (McAllister, 1952). Localities are in White Top Mountain 7.5’ quadrangle.

80-RS-2 Hill 7070 directly east of Rest Spring (about 4 km east of Quartz Spring), near top of exposed section. Conodonts: Idiognathodus spp. (C1)

80-RS-3 Same area as 80-RS-2, middle part of section. Conodonts: Idiognathodus spp. (C1)

80-RS-4 Same area as 80-RS-2, lower part of section. Conodonts: Idiognathodus spp., Neognathodus spp. (C1)

CH-1 Hill (elev. 5840 ft) about 2.5 km north of Quartz Spring (in "Gap Hills" of McAllister, 1952), near top of exposed section which is about 140 m thick. Fusulinids: Beedeina cf. B. apachensis, Fusulinella sp. (F2)

CH-2 Same locality as CH-1 except 10 m lower in section. Fusulinids: Fusulinella sp., Wedekindellina cf. W. cabezasensis. (F2)

CH-4B Same area as CH-1, 15 m above base of section. Conodonts: Juvenile Idiognathodus sp. and Neognathodus sp. (C1)

CH-5 Same area as CH-1, 44 m above base of section. Fusulinids: Beedeina aff. B. occultifrons. (F2)

GH-5A Just below GH-5. Conodonts: Juvenile Idiognathodus sp. and Neognathodus sp. (C1)

Spot localities, northern Santa Rosa Hills

S-0856 Limestone boulder in lower conglomerate unit of Owens Valley Group, west side of Santa Rosa Hills. Fusulinids: Brizites aff. T. ventricosus var. sacramentensis. (F6)

S-1389b Thivipah Limestone, equivalent to Thivipah Member of Keeler Canyon Formation. Fusulinids: Beedeina cf. B. apachensis, Wedekindellina cf. W. cabezasensis. (F2)

APPENDIX 3

Brief descriptions of fusulinid species occurring in the Keeler Canyon and Lone Pine Formations. Species are listed in alphabetical order.

Beedeina aff. B. acme (Dunbar and Henbest)

Our single specimen is similar to the type of Beedeina acme, but it is somewhat more elongate and the chomata appear to be restricted to the inner 2 or 3 involutions.

Occurrence: S-1773. Fusulinid zone F2.

Beedeina cf. B. apachensis (Ross and Sabins)

This form has a simple test with chomata that become massive in the outer involutions as in Beedeina apachensis. This species differs from B. apachensis in its overall larger size.

Occurrence: S-1389b, GH-1. Fusulinid zone F2.

Beedeina cf. B. capsensis (Stewart)

Only one specimen of this species is available for study, but in all respects it resembles this rather broadly defined species.

Occurrence: 82-1-31. Fusulinid zone F2.

Beedeina aff. B. haworthi (Beede)

This species is smaller, generally is more elongate, and has larger chomata than the specimens illustrated by Dunbar and Henbest (1942). It does, however, closely resemble some of the more elongate forms.

Occurrence: 149. Fusulinid zone F2.

Beedeina aff. B. occultifrons (Alexander)

This species is close to but slightly larger than Beedeina occultifrons. It also resembles B. euryteines, but that species probably has better developed chomata which can not be distinguished in our specimens because of poor preservation.

Occurrence: 149, GH-5. Fusulinid zone F2.
Beedeina sp. 1
This small, delicate species bears little resemblance to any other described species. Fusulina sp. 26 of Cassity and Langenheim (1966) is most similar, but that species is more elongate than the present one.

Chusenella cf. C. jewetti (Thompson)
This form rather closely resembles Chusenella jewetti except that in the latter species the volutions generally are more highly arched.

Eoparafusulina aff. E. gracilis (Meek)
This species resembles Eoparafusulina gracilis in many respects, but differs in that the early volutions are less elongate, the specimen is essentially lacking any axial filling, and it has thinner and more delicately folded septa. This species could be a percursor to E. gracilis.

Eoparafusulina sp. 1
Specimens of this species bear a general resemblance to Eoparafusulina gracilis, but the former have a larger proloculus and thicker walls.
Occurrence: S-1208; S-1213 (reworked?).

Fusulinella fugax Thompson
The specimens examined closely resemble Fusulinella fugax in their general form and with diaphanotheca developing only in the outer volutions. Fusulinid zone F1.
Occurrence: S-1208; S-1213 (reworked?).

Pseudofusulina decora Skinner and Wilde
The specimens at hand resemble Pseudofusulina decora in all respects.

Pseudofusulinella parvula Skinner and Wilde
Our specimens correspond with Pseudofusulinella parvula very well.

Pseudofusulinella simplex Skinner and Wilde
Our specimen is very similar to Pseudofusulinella simplex, differing only in having a slightly larger tunnel angle.

Pseudofusulinella sp. 1.
Our forms bear a strong resemblance to Pseudofusulinella acuta Skinner and Wilde, but that species is much larger.
apparently do not persist into the final volutions and no cuniculi have been observed.

*Reticulosepta* sp. 5

This species is unusual in that it possesses a poorly developed juvenarium which is characteristic of *Stewartina*. The development of chomata beyond the juvenarium, however, suggests *Reticulosepta*. Cuniculi occur in the sample, but it is uncertain whether or not they occur in this species.

*Reticulosepta* sp. 6.

No cuniculi have been observed in this species, but its other characteristics suggest *Reticulosepta*. Chomata are less massive than in typical species and are generally confined to the inner volutions. This species is similar to *R.?* sp. 5 but the specimens are much less elongate.
Occurrence: 492, 1090, S-1756, S-1757?, S-1750, S-1767, S-1772, S-1774, S-1780, U-96?. Fusulinid zone F8, F9, 10?.

*Reticulosepta* sp. 7.

This species is characterized by its extreme elongation. In most specimens chomata are limited to the first few volutions.

*Reticulosepta* sp. 8.

This species is characterized by its very well developed, wide chomata that extend through all volutions.

*Schwagerina aculeata* Thompson and Hazzard

The specimen figured here is similar in all respects to the type of *Schwagerina aculeata* except that the former has fewer more tightly coiled initial volutions.

*Schwagerina aff. S. andresensis* Thompson

This species resembles *Schwagerina andresensis*, but our specimens are smaller with more pointed and more tightly coiled inner volutions.

*Schwagerina aff. S. arta* Skinner and Wilde

Our specimen is very poorly preserved, but it is generally similar to *Schwagerina arta*.

*Schwagerina cf. S. bellula* Dunbar and Skinner

Our specimens differ from the types of *Schwagerina bellula* in having very small chomata on the first 2 or 3 volutions and less regularly folded septa. A slight increase in chamber height after the first 2 or 3 volutions suggest a poorly developed juvenarium.

*Schwagerina dunnensis* Sabins and Ross

In all respects this form corresponds to the types of *Schwagerina dunnensis*.

*Schwagerina modica* Thompson and Hazzard

The present specimens resemble the type specimens in all respects.

*Schwagerina aff. S. sublittensis* Thompson, Dodge, and Youngquist

This species resembles *Schwagerina sublittensis* in most respects. It is similar to *S. providens* Thompson and Hazzard except that it is smaller and more delicate.

*Schwagerina turrida* Skinner and Wilde

The present specimens are very similar to the types from the McCloud Limestone differing only in having slightly smaller prodculi. Some specimens are slightly more elongate at all stages of growth.

*Schwagerina sp. 1*

This species resembles *Schwagerina turrida* in many respects, but it has a more elongate test and a much smaller prodculus.

*Schwagerina sp. 2*

This species is similar to *Schwagerina cf. S. bellula* Dunbar and Skinner in having tiny chomata on the first 3 or 4 volutions, but it has more regularly folded septa, no indication of a juvenarium, and the test is shorter and has more rounded poles. It resembles *S. pseudoprinceps* Skinner and Wilde in many respects, but it has less pointed poles and less highly arched chambers.
Schwagerina sp. 3
This form differs from all other described species of the genus. It bears some similarity to Chusenella juveti Thompson, but the early volutions are less tightly coiled and it has more tapered poles.

Stewartina? aff. S.? laxissima (Dunbar and Skinner)
This specimen is similar to the species cited above. It differs mainly in that it has an apparent juvenarium composed of 4 to 5 volutions compared to 2 to 3 in Stewartina? laxissima, it has a thicker wall, it is less elongate, and it has more prominent chomata.

Stewartina sp. 1
This unusual specimen has a very large juvenarium of about 3 volutions with well developed chomata. This species is unlike any previously described species.

Stewartina sp. 2
This specimen differs from all previously described species. It is closest to Stewartina? acutosaxis Magginetti, Stevens, and Stone except that in the present species the outer volutions expand much more slowly.

Stewartina sp. 3
The general form and structure of this species suggests Stewartina convexa Thompson. The present species, however, has a larger juvenarium and is smaller in all other dimensions.

Triticites aff. T. beedai Dunbar and Condra
This species is similar to Triticites beedai except that the overall size of the test is smaller and the proloculus is larger.
Occurrence: 2292, S-1371. Fusulinid zone F5.

Triticites burgessiae Burma
The specimens available are very close to the type specimens.
Occurrence: S-0858, S-1764?. Fusulinid zone F3, F5?

Triticites californicus Thompson and Hazzard?
The poorly preserved specimens at hand match the types reasonably well.

Triticites cellamagnus Thompson and Bissell
The specimens examined are similar to the type specimens of Triticites cellamagnus, but many specimens have an even larger than normal proloculus for this species.

Triticites confertoides Ross
Our specimens are very similar to the types, differing only in having a slightly larger proloculus.

Triticites aff. T. directus Thompson
The present specimens are similar to the above species except that the inner volutions are less elongate.
Occurrence: 1380, S-1765?. Fusulinid zone F6, F7.

Triticites cf. T. hermanni Skinner and Wilde
The specimens studied are poorly preserved, but they resemble T. hermanni rather closely.
Occurrence: 2665?, S-2785, 3549, S-1778. Fusulinid zone F4, F5?.

Triticites aff. T. hobblensis Thompson, Verville, and Bissell
The specimens of this species are poorly preserved, but in a general way they resemble Triticites hobblensis except that they are less elongate.

Triticites aff. T. kelleyensis Needham
Our specimen is smaller, but otherwise is similar to the above species.
Occurrence: S-1753, U38. Fusulinid zone F4, F5.

Triticites meeki Thompson
This specimen is virtually identical with a specimen of Triticites meeki figured by Thompson (1954, pl. 12, fig. 7).

Triticites mulieri Skinner and Wilde
These specimens are similar to the types of this species in all respects.
Occurrence: S-1700. Fusulinid zone uncertain.

Triticites pinguis Dunbar and Skinner
This form appears to be quite variable and numerous taxa have been erected to cover this variability. Some of the present forms are almost identical to the types of Triticites pinguis.
Occurrence: 1380?, 2292, 2665 S-1746, S-1747 (reworked), S-1752, S-1778, U-46?, U-96 (reworked). Fusulinid zone F5, F6, F7?.
Triticitites aff. T. ventricosus var. sacramentensis Needham
The present specimens resemble the above variation in their general characters. Our specimens, however, have more rounded early volutions that are more tightly coiled.

Triticitites wheetstonensis Ross and Tyrrell
This specimen is similar to the types of this species except that it appears to have slightly less pointed poles.

Triticitites sp. 1
These specimens are unlike any other described species, especially in the very rapid increase in height of the outer volutions.

Triticitites sp. 2
This species most closely resembles Triticitites turgida Dunbar and Henbest. However, it also resembles T. confertus Thompson, but has a much larger proloculus and more folding in the axial region. It is shorter, generally has a larger proloculus, and has more highly developed chomata than T. elegantoides Ross.

Triticitites sp. 3
This inflated species has high, thin chomata that distinguishes it from other highly inflated forms such as Triticitites californicus.

Triticitites? sp. 4
This species differs from other described species in having a very wide tunnel angle bordered by small chomata.

Wedekindellina cf. W. cabezasensis Ross and Sabins
The present specimens are very similar to Wedekindellina cabezasensis, differing only in having slightly less axial filling and a slightly larger proloculus.

Wedekindellina? sp. 1
The wall structure in the specimens available is very poorly preserved, but the wall probably contains a dia-

APPENDIX 4
Brief description of conodont species concepts as used herein pertaining only to Pa elements and their occurrence. Multielement taxonomy is not discussed, owing to the paucity of Pb, M, and S elements in the Keeler Canyon faunas.

Adetognathus paralaetus Orchard
A species of Adetognathus with a broad posterior platform possessing long transverse ridges, similar to the fig-
Occurrence: U-94.

Gondolella magna Stauffer and Plummer
Species with distinct transverse ridges, resulting in crenulated upper lateral surfaces of platform.

Gondolella sublanceolata Gunnell
Elongate platform with only faint transverse ridges.
Occurrence: U-14.

Idiognathodus eccentricus (Ellison)
Ornamented idiognathid with a continuous longitudinal trough that extends from the inner adcarinal trough to near the posterior end.
Occurrence: U-12.

Idiognathodus expansus Stauffer and Plummer
Broadly biconvex Pa element with fine transverse ridges and a short carina; adcarinal grooves are short with steep anterior margin; anterior lobe weakly developed and rele-
gated to the anterior end.
Occurrence: U-7, U-11, U-12, U-13, 82-I-30, 82-I-29, 149A, 360A, 680A.

Idiognathodus magnificus Stauffer and Plummer
Pa element characterized by large, laterally projecting inner anterior accessory lobe which distorts the inner platform profile in oral view.
Occurrence: CG-490, U-17, U-18, U-25, U-26; S-1752 (reworked).

Idiognathodus nodocarinatus (Jones)
Pa element with a very short carina and deep trough that extends the length of the broad platform; transverse ridges typically, but not always offset across the median trough; accessory lobes well developed.
Occurrence: 82-I-28, 149A.

Idiognathodus obliquus Kozitskaya
Dextral Pa element displays distinct inward curvature
of the posterior platform with concomitant development of oblique transverse ridges. Well developed inner and outer accessory lobes.
Occurrence: U-5A, U-7, U-11, 149A, 360A.

*Idiognathodus sulciformis* Gunnell

This species is distinguished by the straight, elongate, triangular platform outline with coarse nodes and widely spaced transverse ridges. Adcarinal ridges are typically long and flaring.
Occurrence: U-12, U-13, U-14.

*Idiognathodus n. sp. A* of Barrick et al., 1996

Slightly curved Pa element with a long triangular platform bearing coarse nodes and widely spaced adcarinal ridges. On each side a longitudinal groove extends from the adcarinal trough to near the posterior end of the platform, isolating a row of medial nodes.

*Mesogondolella belladontae* Chernykh

Narrow, elongated species with low, discrete denticles and a large horn-like cusp that is terminally positioned.

*Mesogondolella dentisepara* Chernykh

Species possessing a symmetrical platform with a rounded posterior margin and discrete carinal denticles.

*Mesogondolella lat* Chernykh

Symmetrical platform with angular posterior corner and a relatively small cusp. Platform tapers posteriorly and possesses a medial row of small, closely set denticles that increase in height anteriorly.

*Neognathodus bothrops* Merrill

Pa element possesses lateral parapets that continue symmetrically to the posterior tip of the platform. Posterior terminus of carina separated from posterior tip by small gap.
Occurrence: 82-I-30, U-31 = reworked.

*Neognathodus medadultimus* Merrill

Neognathid in which the outer parapet merges with the carina just anterior of the posterior terminus.

*Neognathodus medexultimus* Merrill

Asymmetrical platform; reduced outer parapet merges with carina approximately at midlength of platform.
Occurrence: 82-I-28

*Streptognathodus aff. S. barskovi* (Kozur)

Dextral elements possess a symmetrical platform well developed anterior parapets, a shallow trough, and numerous elongate transverse ridges. The figured specimen is somewhat narrower than typical *S. barskovi*, but otherwise conforms to the species concept.
Occurrence: CG-1355.

*Streptognathodus brownvillensis* Ritter

Elongate platform with medial row of nodes that correspond in position with short transverse ridges.
Occurrence: S-1794.

*Streptognathodus cancellatus* (Gunnell)

Slender biconvex Pa element with high outer platform margins that join with adcarinal ridges, inner adcarinal ridge forms a frill; lobes generally absent, platform surface concave with one or two longitudinal rows of nodes that extend near posterior tip.

*Streptognathodus confragus* (Gunnell)

Slender Pa element with high anterior platform margins, including an inner frill. Lobes absent or greatly reduced. Carina extends to platform midlength, posterior of which are several continuous transverse ridges.
Occurrence: U-14.

*Streptognathodus constrictus* Chernykh and Reshetkova

Narrow Pa element with slight to pronounced constriction roughly at position of carinal terminus. Stratigraphically lower forms lack well developed adcarinal ridges. Later forms bear flared parapets. Specimens from the Keeler Canyon reflect the more primitive morphology.
Occurrence: CG-1376.

*Streptognathodus costaeabellatus* Chernykh and Ritter

Pa element characterized by a moderately broad platform with a straight inner platform margin and strongly convex outer margin in posterior one-third of platform and reclined posterior transverse ridges.

*Streptognathodus aff. S. cristellaris* Chernykh and Reshetkova

This species was established by Chernykh and Reshetkova (1987) for Asselian forms with a broad platform and inner accessory lobe bearing ridge-like ornamentation oriented normal to the platform axis. Advanced forms possess greatly reduced accessory nodes similar to that figured herein. Node reduction reflects a late stage in the evolutionary history of the nodose *S. wabaumsensis-S. isolatus-S. cristellaris* lineage.
Occurrence: CG-1550.

**Streptognathodus elegantulus** Staufler and Plummer
Unornamented Pa element with a shallow V-shaped trough and relatively short, ridge-like carina. On the holotype there is a slight constriction on the inner side of the platform adjacent to the posterior end of the carina resulting in development of an inner anterior frill.
Occurrence: U-17, U-25, U-26

**Streptognathodus excelsus** Staufler and Plummer
This species is typically broad with a shallow V-shaped trough and well developed inner and outer accessory lobes.
Occurrence: U-17, U-25, U-26, U-34.5, U-36.

**Streptognathodus fuchengensis** Zhao
This concept is applied herein to streptognathodid with a nearly flat platform surface that increases in width posteriorly. The platform displays a distinct inward curvature and rounded posterior termination.
Occurrence: 765, CG-1521.

**Streptognathodus fusus** Chernykh and Reshetkova
Nearly symmetrical Pa element with a shallow, slit-like median trough and elongate transverse ridges oriented normal to the platform axis. The inner parapet is larger than its inner counterpart.

**Streptognathodus aff. S. longilatus** Chernykh and Ritter
As originally conceived, this is an unornamented streptognathodid with long adcarinal ridges and a relatively broad posterior platform bearing a distinct constriction in the anterior one-third. The specimen from S-1794 lacks the long adcarinal ridge, but resembles *S. longilatus* in platform shape and age.
Occurrence: S-1794.

**Streptognathodus longissimus** Chernykh and Reshetkova
Unornamented streptognathodid with an elongate, narrow sinistral Pa platform element. Carina is short and adcarinal ridges are generally well developed.

**Streptognathodus pawhuskaensis** (Harris and Hollingsworth)
Unornamented streptognathodid with a deep U-shaped trough.

**Streptognathodus tenulaleve** Chernykh and Ritter
Species of narrow unornamented *Streptognathodus* with nearly symmetrical platform and flat oral surface.

**Streptognathodus virglicus** Ritter
Unornamented species with shallow V-shaped trough and elongate transverse ridges. Platform ranges from wide to narrow.
Occurrence: 99-I-612 and U-57 (reworked); S-1752, S-1794, CG-0, 98-I-928.

**Streptognathodus** n. sp. 1
Elongate, unornamented species with short carina, well developed parapets, and a slight inward flexure of the axis. This species resembles *S. simplex* and *S. elongatus*, but is younger (Sukmarian) than the type materials of these species (late Gzhelian). They resemble specimens from the Sukmarian Eiss Limestone of Kansas (Boardman, personal communication, 2001).

**Streptognathodus** n. sp. 2
Broad unornamented species with a distinct inner frill in the anterior portion of the platform. Trough slit-like and narrow with numerous elongate transverse ridges. This species resembles Asselian *S. fusus* and *S. postfusus*, but is herein tentatively distinguished by its Sukmarian age. Similar morphotypes were collected from the Sukmarian Eiss Limestone in Kansas (Boardman, personal communication, 2001).
Occurrence: 97-I-901.

**Streptognathodus** n. sp. A of Chernykh and Ritter, 1997
Streptognathodid with an oblique anterior termination and symmetrical trough.
Occurrence: S-1785.

**Sweetognathus merrilli** Kozur
Sweetognathid with no gap between the carina and denticles of the free blade. This feature is hard to evaluate in many of our specimens due to poor preservation of the platform anterior.

**Sweetognathus whitei** (Rhodes)
Sweetognathid with elongate transverse ridge oriented normal to platform axis.

**Wardlawella expansa** (Perlmutter)
Small Pa element with fused carina ornamented with
micro-pustules. This species evolved from *Diplagnostodus* and was the evolutionary link to most Permain gnatho-
dids.

Occurrence: 99-L-609, 76.

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